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Waste Management Consultants

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

FINAL REPORT

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1.0 EXECUTIVE SUMMARY

This report summarizes the results of a program to design and test formulations of geopolymeric concretes for use in site rehabilitation work at the Halifax airport. Outcrops of pyritic slate exposed during construction activities have been demonstrated to be responsible for acidic leachate draining into the watershed surrounding the airport. This leachate has resulted in widespread environmental damage, including mass fish kills. The situation has been under review by Environment Canada in conjunction with Transport Canada for a number of years. As part of these investigations, D. Comrie Consulting Limited (DCCL) was contracted by Supply and Services Canada (SSC) to perform research into formulations of geopolymeric cements.

An examination of the use of various admixtures, including fly ash, silica fume, and conventional aggregates, for incorporation into a cement which could be applied to the Halifax airport slates commenced in December, 1988. The focus of early testing was to assess the effects of the various admixtures on timing of development and ultimate strength of the final product. Assessment of results was initially qualitative; discriminant selection of certain formulations for further testing was accomplished over the following months.

It was found in this initial phase of the program that introducing fly ash at the expense of geopolymer powder likely has a more detrimental effect on strength than ash introduced at the expense of geopolymer liquid. Increasing the concentration of geopolymer liquid (GPA) at the expense of fly ash has a more positive effect on strength than increasing it at the expense of aggregate.

Following the initial examinations, compressive stress testing of selected mixes was undertaken. The results of this work were then selected for application testing using modified shotcreting apparatus. At this time, freeze-thaw prisms and conventional cylinders for compressive stress testing were prepared and submitted to CANMET Laboratories for physical testing using ASTM 666 test procedures.

The submitted prisms failed freeze-thaw testing after 30 cycles. Data pertaining to the mode of failure was not provided. As a result of the prism failure, compressive stress testing was not performed on the shotcreted cylinders.

It was found that, when applied using a shotcrete gun, the geopolymer could be adhered to surfaces of any orientation with no slump occurring.

Concurrent with the physical testing of the submitted material, DCCL continued testing of formulations of geopolymeric cements with the aim of improving reactivity of the material. Following notification of prism failure, a second series of prisms was prepared and submitted to CANMET for freeze-thaw testing. These prisms utilised new formulations of geopolymeric cements, conventional aggregates, and admixtures of silica fume, air entrainer, and super-plasticizers. Along with this testing, the resultant material was subjected to

flexural and compressive strength testing.

The geopolymer formulation used in the freeze-thaw prisms was then utilised in a full-scale application using modified shotcreting apparatus. The material was successfully applied to a rock face, a rock ledge, and a section of structural road. Cores taken from this application were subjected to 48-hour compressive strength testing.

The submitted prisms successfully completed freeze-thaw testing in September, 1990. Measurement of temporal variation of physical parameters produced some interesting results, since the change in physical parameters relative to the start of testing reversed itself for some prisms. Reversals can generally be correlated with prisms that had commenced freeze-thaw testing prior to completing a standard 28-day cure period. It is therefore probable that these prisms were still undergoing curing at the time of commencement of freeze-thaw testing.

The Durability Factor of the geopolymer-based prisms returned values ranging from 85 to 104. Discarding those prisms which may have been undergoing curing at the time of freeze-thaw testing, the range of Durability Factors is from 95 to 104. This compares favourably with data obtained in testing of prisms composed of conventional cements and similar admixtures to those used in this study.

Compressive and flexural stress tests performed on prisms from the same series returned values ranging between 26.5 to 30.9 MPa and 3.4 to 4.0 MPa, respectively.

The shotcrete testing indicated that the material could be applied quickly and efficiently using slightly modified shotcreting apparatus. Again, no slump was noted due to the extremely quick set time of the material. Compressive stress tests performed after 48 hours returned values of 34.5 and 36.9 MPa respectively.

The testing and formulation program undertaken by DCCL indicates that geopolymeric concretes behave in a similar fashion to conventional cements. Advantages of geopolymer-based cements include extremely fast set time and very fast development of significant strength. These attributes allow application in areas where minimal service interruptions are desired. Additionally, the lack of slump with the material allows efficient application to capping of surfaces with any orientation.

An analysis of costs associated with a large-scale program to cap exposed outcrops of pyritic slate at the Halifax airport indicates the cost of the product, assuming a mean application thickness of 0.10 metres (0.33 ft), would be \$39.10 per m^2 or \$3.63 per ft^2. Decreasing the mean application thickness by 50% to 0.05 metres would reduce the unit area cost to \$19.55 per m^2, or \$1.82 per ft^2.

2.0 INTRODUCTION

This report summarizes the results of a program to design a mix of geopolymeric concrete to be considered for use as a capping material for outcroppings of pyritic slate at Halifax International Airport. Data pertaining to mix formulations, shotcrete testing, and compressive strength results are presented. A discussion of the results relative to the proposed application will be undertaken.

2.1 PROJECT BACKGROUND

Acid drainage from outcroppings of pyritic slate at the Halifax Airport resulting in large scale fish kills and other environmental damage has been documented since 1960. The slate forms a 2.5 km wide band which stretches through the airport area and carries anomalous concentrations of aluminum, iron, manganese, cobalt, nickel, lead and arsenic. Studies by Environment Canada have shown that blasting and excavation of the slate during the construction of the airport, local highway and other nearby facilities have exposed large areas of rock, producing contamination in local ground and surface water. Acidified groundwater, rich in heavy metals, drains to the nearby Salmon River watershed. Further discussion of the site can be found in Guilcher (1987), Macready (1987) and Worgan (1987).

The situation has been under review by Environment Canada, in conjunction with Transport Canada, for a number of years. Part of Transport Canada's response to the situation has been the construction of a lime treatment facility designed to neutralize the acid drainage from the site. Unfortunately, the lime sludge collected from the treatment facility can also be considered a potential environmental hazard, and poses additional disposal problems.

As part of these investigations, there has been research into potential materials for capping the outcrops to restrict water access and consequent leaching potential of the slate outcrops. A 7 ha waste rock pile has already been capped with clay at a cost of $800,000. Ideal materials for this application require low permeability and high strength to ensure proper capping.

As part of this research, D. Comrie Consulting Limited (DCCL) was contracted by Supply and Services Canada (SSC) to conduct experiments into formulations of geopolymeric concrete with the aim of ascertaining the potential for application of geopolymers to the Halifax Airport problem. The scope and general conditions of the study undertaken by DCCL are described in detail in the initial contract document (Supply and Services Canada, 22.12.88). A copy of the initial contract is included in Appendix 1. Briefly stated, DCCL was contracted to examine different formulations of geopolymeric cement and the use of concrete admixtures such as fly ash, silica fume and slag with geopolyers to create a viable capping material. As part of the study, data pertaining to the mechanical properties

(compressive and flexural strength, modulus of elasticity, freeze-thaw durability, thermal expansion coefficients) of the geopolymeric concretes were to be developed. Field testing of the geopolymer to assess the capability for application of mixes by a shotcrete gun was also carried out during this program.

Initially, all work pertaining to the test program was to be performed by DCCL under the supervision of a designated representative of Transport Canada. Subsequent amendments to the initial contract document did not alter the scope of the program; however, the contract amendment of 28 August 1989 assigned testing of geopolymer formulations to the CANMET laboratories under the supervision of the Scientific Authority.

3.0 GEOPOLYMER FORMULATIONS

3.1 GENERAL

Geopolymeric-based concretes have been under investigation by DCCL and associated companies for a number of years. Various formulations have been tested and modified using information acquired through laboratory research and full-scale application in a wide range of environments.

Geopolymeric concretes are based on inorganic binders - cementitous agents which react together to provide high early strength. The term "geopolymer" has been coined to describe these binders, since it is believed that the reactions involved create a polymeric arrangement of inorganic molecules.

Preparation of inorganic binders is carried out by combining liquid and powder portions; blending can be done using conventional cement mixing technology. The thick, viscous liquid which results can then be combined with aggregate to form a geopolymeric concrete. Mix designs can be created to form concretes with consistencies amenable to pouring, extruding or shotcreting. A mildly exothermic reaction in the alkali activated mixture is accompanied by hardening and polycondensation.

The inorganic binder reaction occurs as a result of reacting alumino-silicate oxides with alkali (NaOH, KOH) and soluble alkali polysilicates. It is thought that SiO_4 and AlO_4 tetrahedra result from this reaction and are linked by shared oxygens to form a polymeric network. Positively charged ions, such as sodium, potassium, lithium, calcium or barium, must be present in the framework cavities in order to achieve charge balance (Figure 1).

The ability of binders to resist acidic attack is demonstrated by the performance of solidified material during acid based leachate tests. Waste products containing heavy metals or other toxins have been substituted for aggregate in geopolymeric cements, and then subjected to

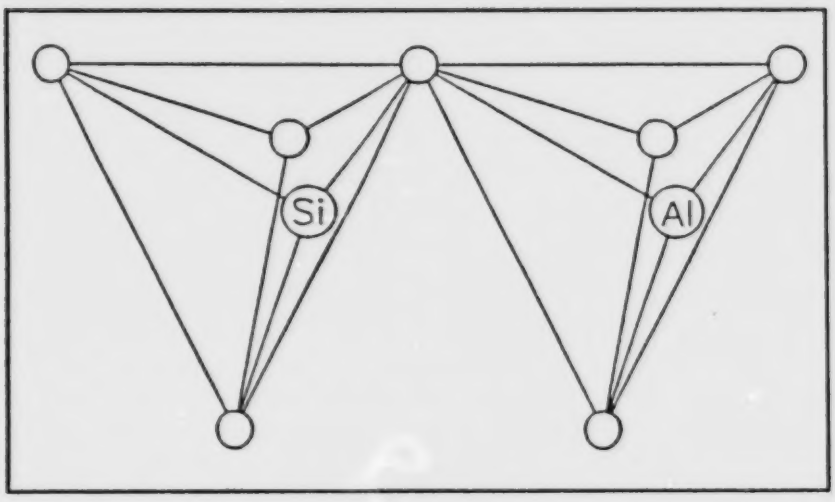


Figure 1: AlO_4 and SiO_4 tetrahedra - basis of the geopolymeric network

leachate tests carried out in accordance with Ontario's Ministry of Environment Regulation 309 guidelines. The guidelines prescribe that samples be first crushed and then subjected to leaching in acetic acid. Concentrations of a range of metals and toxins in the leachate are then measured, and levels compared to maximum effluent concentrations set by the Ministry of Environment.

There is a wide range of wastes which remain bound into geopolymeric cements, even under the conditions dictated by leach testing. This suggests that the binder is capable of resisting the acidic attack encountered in the testing environment.

Throughout this report reference will be made to geopolymers and inorganic binders. Several different compositional designs have been developed for geopolymers during their evolution; these include GP50 and GP52, both of which were used in this work program. DCCL also uses several compositional designs referred to as "inorganic binders" (the term is somewhat more descriptive than "geopolymer"), which were developed on the same principles as geopolymer. Varieties of inorganic binders include IB100 (powder and liquid portions), IB7030 (liquid only), INORBOND and IB dry and liquid activators. Both geopolymers and inorganic binders are proprietary products.

3.2 PHASE 1 PROGRAM

A mix design program for this project was implemented in late 1988, following the assignment of the initial SSC contract. Efforts first focussed on determining the effect of the addition of different constituents, such as clay, fly ash, silica fume and sand, on the nature of a geopolymeric cement. A range of mixtures created with different amounts of these components was created, and evaluated on a semi-qualitative basis.

Following this program, a set of mix designs was used to create hand sample sized cylinders, which were in turn subjected to compressive strength testing at an age of two days. Standard 4x8-inch cylinders were also developed from testing; these cylinders were obtained both during lab scale mix design and from larger scale trials. Data pertaining to mix formulations for this phase of work is presented in Tables 1-7, Appendix 2.

This stage of the program was completed with the fabrication of prisms and 4x8-inch cylinders for freeze-thaw trials and compressive strength testing, respectively.

3.2.1 FREEZE-THAW PRISMS-PHASE I

Preparation of the first prisms to be submitted to freeze-thaw testing was carried out in October of 1989. Six prisms were prepared, in accordance to ASTM 666 specifications; several 8-inch cylinders were also prepared for compressive strength testing. Shotcrete apparatus was used to deliver the geopolymeric cement to both the prisms and cylinders.

The mix design used for the shotcreting of this set of prisms was as follows:

INORBOND 100	
Powder	12.5 weight percent
Liquid	2.5 weight percent
Sand	42.5 weight percent
Pea Gravel	42.5 weight percent

Shotcreting was carried out with the assistance of an outside firm subcontracted to DCCL. Dry ingredients were combined in the hopper of the shotcrete machine, with liquid binder added at the shotcrete gun nozzle. It was found during the work that the cement stiffened almost instantly upon application; slump tests were, of course, impossible.

After the application was completed, the cylinders and prisms were transported from the work site in Kitchener to the offices of DCCL and covered with damp burlap for curing. The burlap covering was periodically moistened over the following 14 days, before the cylinders were transported to CANMET's Material Testing laboratories in Ottawa for freeze-thaw testing. It was agreed that the cylinders be retained by CANMET for testing once the prisms had successfully passed the freeze-thaw trials.

3.2.2 FIELD TRIALS - PHASE I

The field applications which were conducted during Phase I of the program include both pours and shotcreting trials.

The first field application for geopolymer was at the Hope Brook mine, Newfoundland, during the summer of 1988 (DCCL, 1988). Although the application was not funded by this contract, it provides interesting background information, especially since the problem at the minesite was one of acidic drainage.

Hope Brook Mine Application

Water draining into the Hope Brook mine is pumped to surface, through a drainage ditch created by blasting through bedrock, and into a holding pond before pumping to the tailings disposal area. Leaching of sulphide-rich rocks at the minesite means that the drainage water takes on an acidic nature.

By 1988, minesite staff and provincial officials had expressed concern that acid drainage was leaking through the ditch into nearby streams, which in turn drained to a local salmon river. Water monitoring stations between the river and the ditch confirmed the problem. Bags of lime were dumped into local creeks as a stop-gap measure.

Three tonnes of geopolymer (GP50) were brought onto the minesite and mixed with sand and 3/4-inch crushed stone. A minesite cement truck was used for both mixing and transportation of the blend; geopolymer powder and liquid were added first, followed by addition of sand and gravel from the minesite batch plant. A layer of concrete, about 2 to 3 inches in thickness, was applied along a 150 foot section of the ditch. Heavy rains following the application caused flooding of the ditch with about a foot of fast flowing water within 12 hours of the operation. Inspection on the following day showed that the concrete set well in spite of the flooding; test cylinders taken from the pour and tested by Newfoundland Geosciences Ltd. showed compressive strengths of 23.4 MPa.

INORBOND Field Test - Pour Application

Bench scale work conducted in the Halifax Airport program was followed by a field test using an IB100 based concrete during April of 1989. Binder, sand and 3/4-inch crushed gravel was blended outdoors in an electric powered portable cement mixer; the outside temperature was about 55 ^{o}F. After approximately five minutes of blending, the mix was poured into molds for bricks (4x8x2-inch), flagstones (18x18x2-inch) and standard 4x8-inch concrete testing cylinders.

A piece of steel re-bar was inserted into one cylinder; in spite of the cool temperatures, the re-bar could be used to pick the cylinder up within half an hour. Bricks and flagstones were de-molded half an hour after pouring.

INORBOND Field Test - Shotcrete Application

Geopolymeric cement was first shotcreted in October of 1989 during the preparation of Phase I freeze-thaw prisms. A more thorough examination of the use of shotcreting technology for the application of geopolymer was carried out in December of 1989. This work, coordinated with an outside firm subcontracted to DCCL, involved the application of

approximately 120 kg of an INORBOND-based mortar. The mix design used is as follows:

INORBOND A (7030 liquid)	10kg
INORBOND B (powder)	60kg
Water	20kg
Pea gravel	180kg
Concrete Sand	180kg

Concrete sand, INORBOND powder and liquid were all combined in the shotcrete hopper and pumped approximately 10m to the application area.

This field test proved to be a dramatic demonstration of how the use of high-pressure shotcreting equipment can minimize the setting time of a geopolymeric concrete. In fact, it was found that the INORBOND mortar set almost instantly after application. Using a wall-mounted plywood board as a target, the shotcrete operator was able to construct a 2-inch thick coating over the vertical surface of the board, as well as creating 6-inch diameter cylindrical mounds which protruded up to 18 inches from the wall, with their long axis oriented parallel to the floor. Cylindrical mounds up to 36 inches in length were also constructed using the floor as a base instead of the plywood. A quantity of the mortar mixture was also applied to a wire framework hung from the ceiling - the result was a suspended layer of shotcrete.

Iron Hydroxide Sludge Solidification

Samples of the iron hydroxide sludge produced by the Airport on-site lime treatment facility were provided by Paul Goudey at the Halifax Airport. Although solidification of the sludge was not a focus of this program, it is significant to note that a preliminary program was successful in solidifying the sludge using a variety of geopolymer-based mix designs. The mix designs, which also incorporate sand and fly ash, can be found in Table 7. Three solidified samples were returned to Mr. Goudey, with a recommendation that they be subjected to leachate testing in order to evaluate the effectiveness of the geopolymeric mix.

3.3 PHASE 2 PROGRAM

The Phase 2 program commenced in early 1990. At that time, additional laboratory testwork into geopolymer formulations was undertaken with the aim of improving reactivity, cure time, timing of development of significant early strengths, and improving the ultimate strength of the geopolymer. Following evaluation of the results, the final product of this phase of experimentation was submitted to Transport Canada for freeze-thaw testing.

In order to complete Phase 2 testing, the geopolymer formulation was tested in a full-scale

trial involving application of the material by shotcrete gun. Cores taken from these trials were subjected to compressive strength testing to evaluate the timing of compressive strength development.

3.3.1 FREEZE-THAW PRISMS-PHASE 2

Preparation of prisms for freeze-thaw testing commenced in June, 1990. Two sets of six prisms were poured. In each set, the prisms were prepared as six separate batches. The use of separate batches was deemed necessary due to the speed with which the mix became too viscous to pour. A total of five prisms, 2 from the first set and three from the second set, were submitted to CANMET for testing.

The preparation of the prisms was performed in accordance with ASTM 666 standards. Table 8 summarizes the constituents of the mixes.

Mixing of the material for testing was done at DCCL using a Lightnin mixer with a capacity of 0.02 m^3. After pouring, the prisms were trowelled and covered by plastic. The prisms were allowed to attain surface solidification prior to relocation to a storage area. The prisms were demoulded at a variety of different times to assess how this may affect the behaviour of the Inorbond. Table 9 summarizes the surface solidification times and dates of prism pouring and demoulding. Following demoulding, the prisms were completely wrapped in plastic and returned to storage. Submission of the prisms to CANMET was completed on July 13, 1990.

Assessment of slump for each of the mixes was not performed. The omission of this test was for practical reasons; the material underwent liquid-solid phase transition too quickly for slump to occur.

TABLE 8. COMPOSITION OF FREEZE-THAW PRISMS SUBMITTED TO CANMET

PRISM	INORBOND 700 (kg m^{-3})	INORBOND 7822 (kg m^{-3})	SILICA FUME (kg m^{-3})	SAND (kg m^{-3})	COARSE AGG. (kg m^{-3})	A.E.A* (l m^{-3})	SPN** (l m^{-3})
COM-1	425	500	75	1000	-----	0.330	0.825
COM-2	425	500	75	1000	-----	0.330	0.825
F2-1	450	530	80	715	285	0.300	0.420
F2-2	450	530	80	400	600	0.260	0.900
F2-3	450	530	80	200	800	0.300	0.420

* Air Entrainer
** Super Plasticizer

TABLE 9. SURFACE SOLIDIFICATION, DATE OF PREPARATION AND DATE OF DEMOULDING

PRISM	SURFACE SOLIDIFICATION (minutes)	DATE POURED	DATE DEMOULDED
COM-1	10.2	07.06.90	20.06.90
COM-2	9.5	07.06.90	20.06.90
F2-1	4.5	24.06.90	26.06.90
F2-2	6.0	28.06.90	29.06.90
F2-3	4.2	30.06.90	04.07.90

3.3.2 SHOTCRETE TRIALS-PHASE 2

Subsequent to the Phase 1 shotcrete trials, a second larger scale trial was performed in early July, 1990, by DCCL and another outside firm. For this test, a total of 1,000 kg. of INORBOND and 4,000 kg. of locally available aggregate was applied to a rock face, a rock ledge, and to a road surface.

The dry materials were mixed in a 7 m^3 cement mixer and dumped directly into the shotcrete hopper. The material was then auger fed to the pressurization chamber. The dry material was driven through a 12-metre length of 7.6 cm hose at an average pressure of 1340 KPa (see Plates I, II, III and IV).

Addition of the INORBOND liquid was accomplished at the nozzle of the shotcrete apparatus using an air-driven Sandpiper pump. The amount of liquid introduced to the dry mixture was controlled by the operator using a standard faucet.

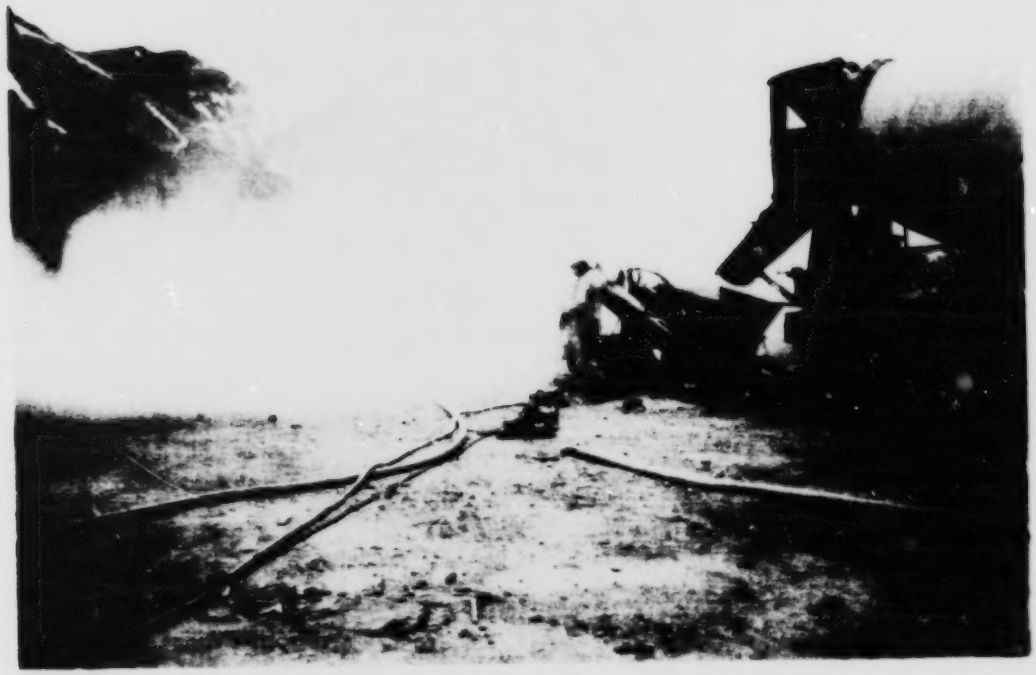


Plate 1: Phase II Shotcrete Program. General view of shotcrete feed apparatus.

Plate 2: Phase II Shotcrete Program. Shotcreting of 19 m^2 section of structural road. Small diameter hose is used for delivery of liquid.

Plate 3: Phase II Shotcrete Program. General view of completed section of structural road.

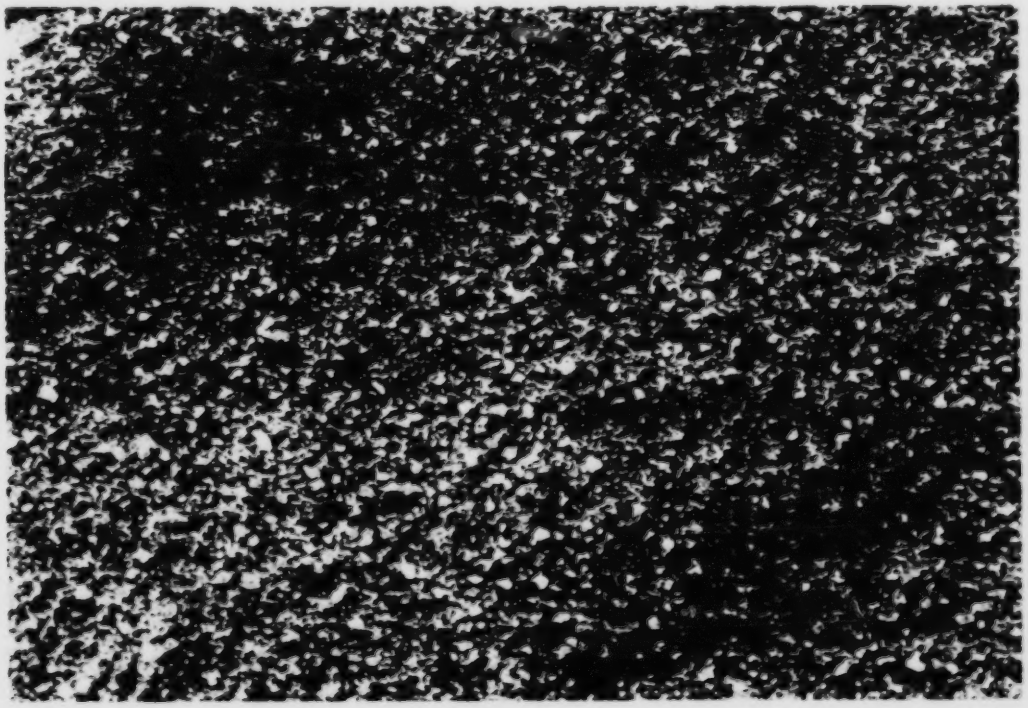


Plate 4: Phase II Shotcrete Program. Detailed view of shotcreted road section. Horizontal width is approximately 20cm.

4.0 TESTWORK

4.1 PHYSICAL TESTING PHASE 1

Physical testing during Phase 1 was carried out in several stages. First, the initial mix designs were subjected to a semi-qualitative evaluation (Tables 1a and 1b, Appendix 2), in which samples were rated on a scale of 1-5 (5 being the highest, or most favourable) for thickness of the mix, setting time, surface cracking, 1-day hardness and 7-day hardness. The goal of the program was to identify formulations which could be easily handled, set up within a period of a few hours, achieved high hardness within 1 day and exhibited good surface characteristics. Additional testwork focussed on the use of high fly ash contents was also carried out, using more subjective evaluations.

The second stage of testing can be considered more quantitative, since samples were submitted to Golders Associates of Mississauga for compressive strength testing, in accordance with CAN 3-A23.2-14C M77. Two types of molds were used to create the specimens for compressive strength testing - standard 4x8-inch molds, and smaller, hand sized cylinders.

As discussed in an earlier section, Phase 1 concluded with the preparation and submission of prisms and cylinders to CANMET's Material Testing laboratories for freeze-thaw testing. Since it was found that the prisms submitted for testing failed ASTM 666, it was decided not to go ahead with compressive strength testing of the cylinders provided.

4.2 PHYSICAL TESTING-PHASE 2

4.2.1 FREEZE-THAW PRISMS

The relevant data pertaining to the 5 prisms submitted to CANMET for freeze-thaw testing are presented in Table 10. Relevant physical parameters were measured at 0, 150, and 300 cycles of freezing and thawing.

4.2.2 PHASE 2 SHOTCRETE TRIALS

Experimentation with the liquid feed indicated that optimum results were obtained when the mixture achieved a slightly moist consistency at the nozzle. Problems encountered with the machinery and inefficient delivery of shotcrete mix to the nozzle required the use of larger amounts of liquid than had originally been planned for in order to achieve this consistancy.

During application of the shotcrete, surface solidification times were noted for the mixture. It was found that initial solidification times ranged from 1.5 to 5 minutes. Observations of the shotcreted material over the ensuing 48 hours (after application) were made to assess the curing process and to ascertain the presence or absence of surficial micro-fracturing which may be expected to occur when working with quick set concretes.

TABLE 10. MEASURED PHYSICAL DATA FOR 5 PRISMS SUBMITTED TO CANMET

# OF CYCLES	WEIGHT (kg) 0	150	300	LENGTH (mm) 0	150	300	LONGITUDINAL FREQUENCY ($m\ s^{-1}$) 0	150	300	ULTRASONIC PULSE VELOCITY ($m\ s^{-1}$) 0	150	300
COM-1	6.077	6.004	5.957	363.4	363.5	363.5	3660	3664	3640	3236	3285	3285
COM-2	5.910	5.876	5.837	363.1	363.2	363.2	3696	3674	3670	3209	3247	3247
F2-1	6.514	6.380	6.274	363.4	363.7	363.7	3645	3630	3710	3368	3465	3395
F2-2	6.327	5.998	5.900	362.7	362.8	362.8	3490	3490	3266	3577	3462	3425
F2-3	6.480	6.493	6.430	363.4	363.9	363.9	3385	3430	3120	2819	3302	3365

5.0 RESULTS

5.1 PHASE 1 WORK

As previously noted, the detailed results of geopolymer formulations relevant to the Phase 1 testwork are included in Appendix 2. Progress reports submitted to SSC during the Phase 1 testwork are included in Appendix 3. Of particular note are the following results:

1) During the first work to address the behaviour of geopolymer and inorganic binder with other reactive and non-reactive constituents, products of different mix designs were evaluated on the basis of viscosity, set time, cracking and hardness. Optimum product was produced by mixes 10-25-2, 10-25-5, 11-10-5, 11-25-1, 11-25-2, 11-25-3 and 11-25-4 (Appendix 2, Tables 1a and 1b). These mixes used either Inorbond or geopolymer as an activator. Specifically, the mixes included amounts of Type D Inorbond, slag, silica fume, calcium hydroxide, IB Liquid Activator and caustic; each mix contained approximately 60 weight percent sand. A comparison of samples 11-10-5, 11-25-1 and 11-25-2 suggests that the concentration of caustic used and the use of calcium hydroxide are not critical to the physical characteristics of the product.

2) Qualitative evaluation was also made of a range of samples which incorporated large amounts of fly ash (Tables 2 and 4). Moldability, hardness and binder requirements were used as evaluation criteria. This work is the subject of an interim report appended in Appendix 3; geopolymer contents were reduced to between 13.5 weight percent (for minimal strengths and longer curing times) and 18.1 weight percent (ideal physical characteristics). During the program, several observations regarding constituents were made:

   Fly Ash - absorptive characteristics of course require higher binder contents with increased ash content; using sufficient addition of binder, mixes could be created (without forsaking hardness and moldability) with up to 54 weight percent fly ash.

   Clay - clay was found to contribute significantly to moldabilty.

   Silica Fume -silica fume appeared to contribute to hardness, ease of mixing and moldability, although water contents had to be increased as a result of its use.

   Water - amounts of water used are critical, with as little as 5 weight percent making a dramatic difference in the nature of the mix.

3) The relationship between Type F Inorbond powder, liquid and cement is examined in Tables 4(c), 4(d) and 4(e); setting times increase with decreasing cement or increasing liquid contents.

4) Compressive strength testwork for Phase I is summarized in Tables 5(a), 5(b) and 5(c); some points are graphically represented in Figures 2 through 6. Several conclusions can be drawn from this data, including:

- That strength increases with the proportion of coarse aggregate (Figure 2) and decreases with increased use of fine aggregate (sand). This is, of course, as expected.

- That the length:diameter ratio of cylinders used for testing does not appear to show correlation with compressive strength (Figure 3). This suggests that comparisons can be made among the small hand sized cylinders with low length:diameter ratios.

- That compressive strength increases slightly with density (Figure 4). This relationship could reflect any number of factors, including the ability of more dense coarse aggregate to lend strength to the mix.

- That, in the ranges examined, introducing fly ash at the expense of geopolymer powder (GPB) may have a more detrimental effect on strength than introducing ash at the expense of geopolymer liquid (GPA), as shown in Figure 5(b).

- That, in the ranges examined, increasing the concentration of geopolymer liquid (GPA) at the expense of fly ash has a more positive effect on strength than increasing it at the expense of aggregate (Figure 5b). This seems logical, since aggregate likely contributes to strength to a greater degree than fly ash.

- cements can attain approximately 25% of a 31 day 33.6 MPa compressive strength during their first 3 days of curing and 60% after 7 days (Figure 6). Water has a dramatic effect in cutting strengths.

5) The Phase I freeze-thaw prisms submitted to CANMET underwent structural failure after 30 cycles of freezing and thawing. The mode of failure was not determined.

6) Field trials have indicated that some geopolymeric cements can set in spite of cold temperatures (50 ^{o}F range) or in spite of immersion in water shortly after pouring.

Figure 2: Coarse Aggregate Content
vs Compressive Strength

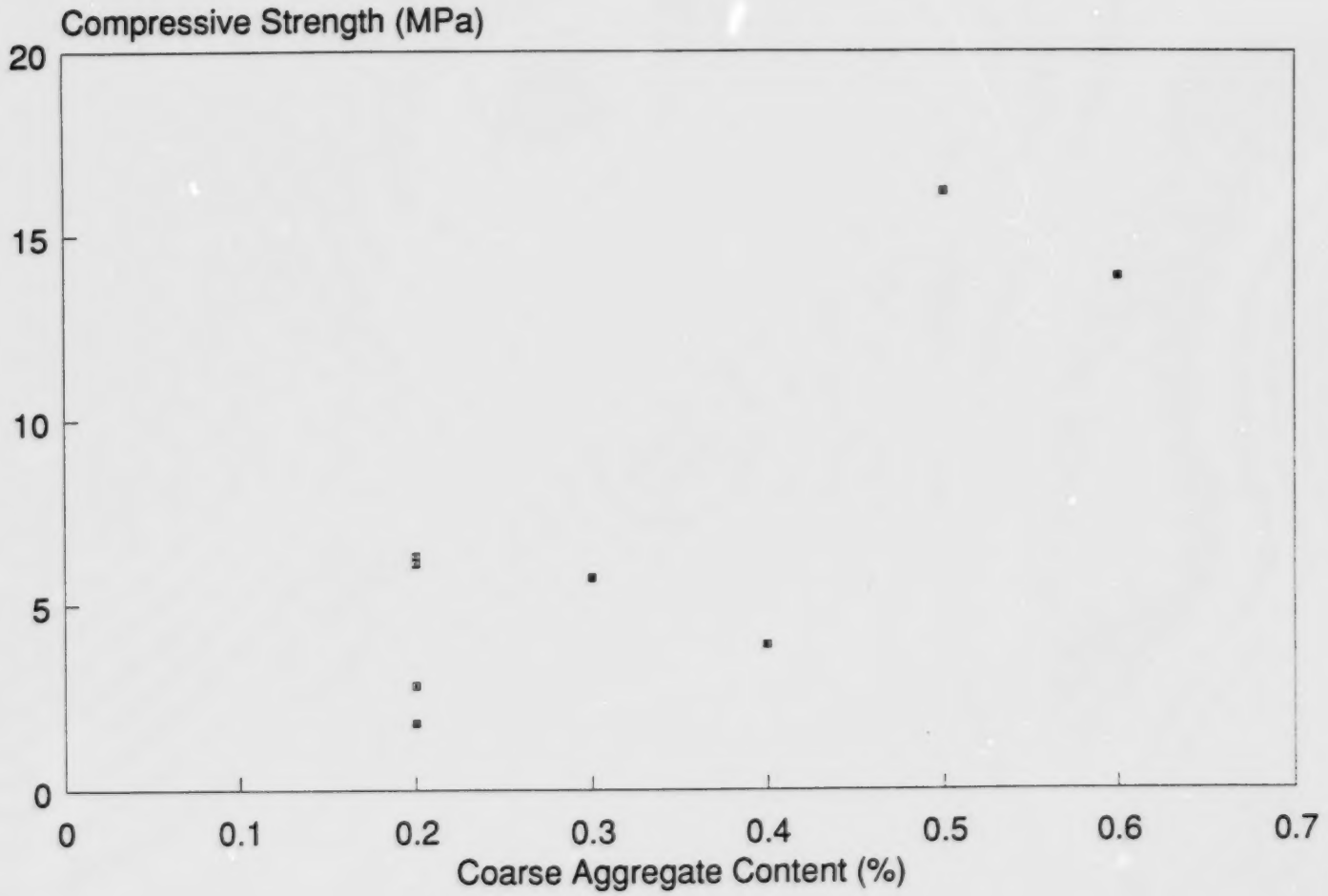


Figure 3: Length:Diameter Ratio vs
Compressive Strength

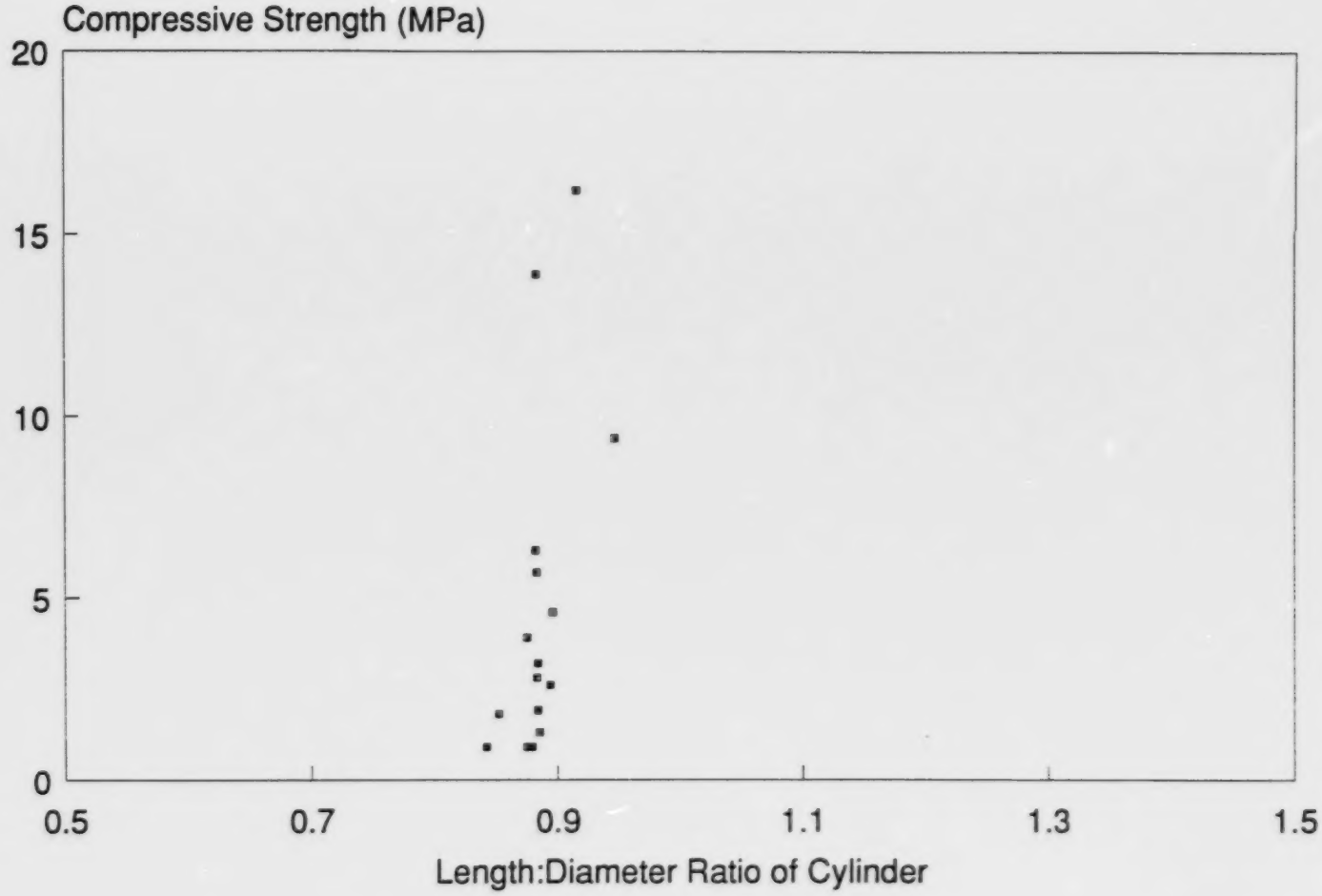


Figure 4: Density vs
Compressive Strength

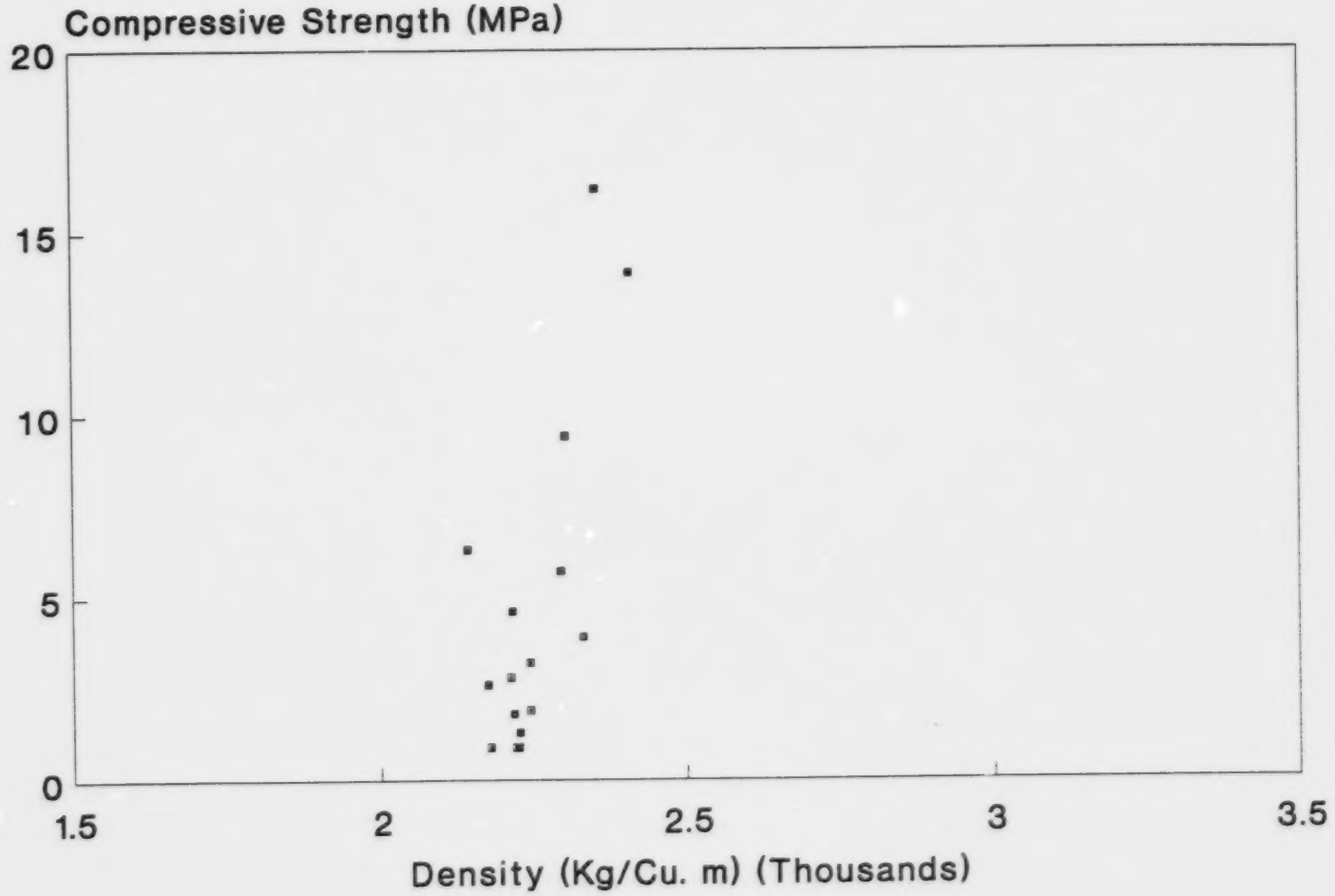


Figure 5(a): Fly Ash Content vs Compressive Strength

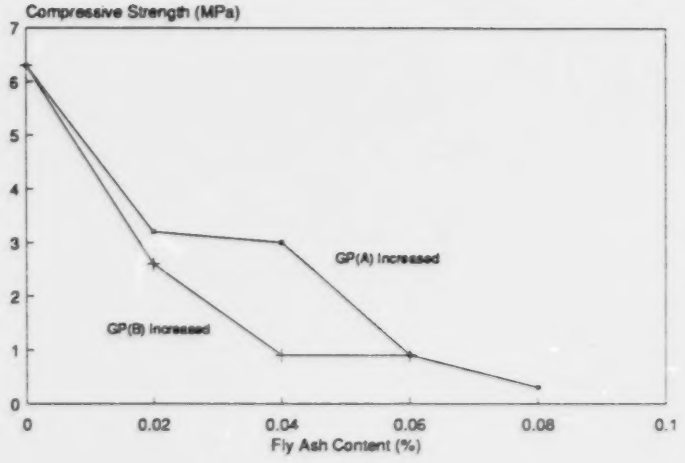


Figure 5(b): GP(A) Content vs Compressive Strength

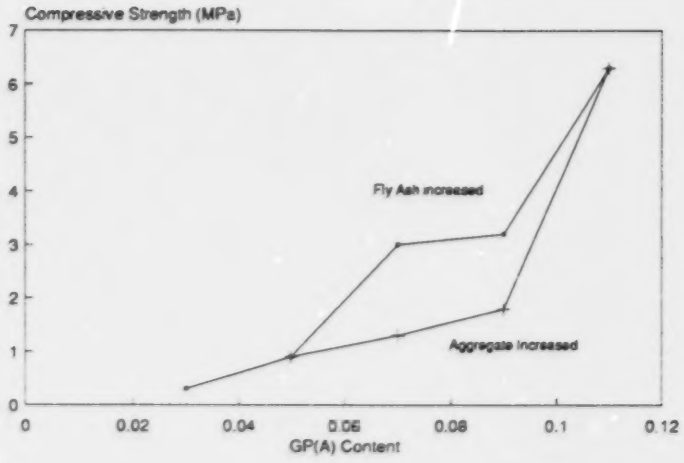
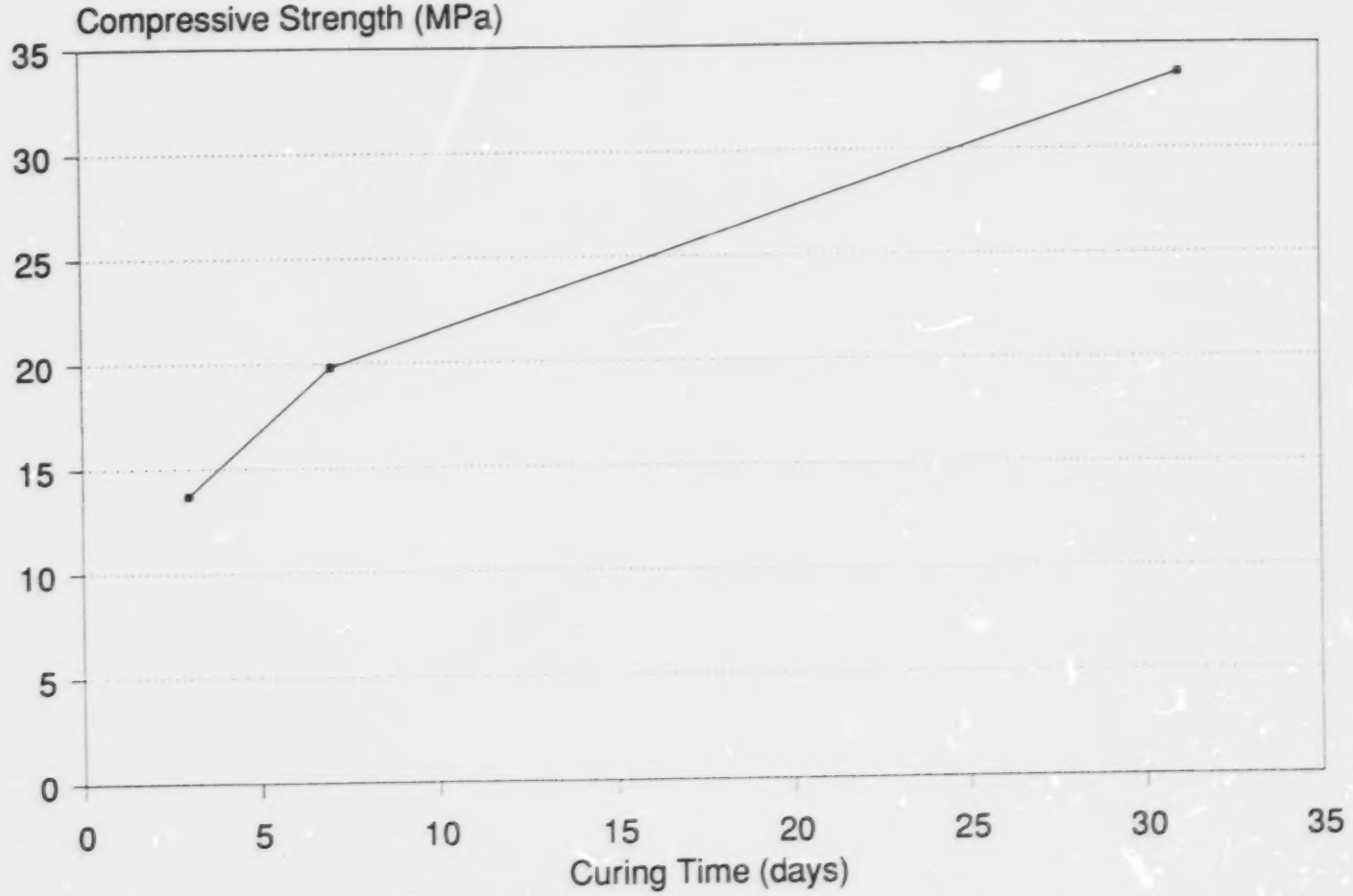


Figure 6: Change in Strength over Time
(sample 4-7-2)



7) In trials with a shotcrete gun, it was found that the material responded well with minimal slump and almost instantaneous set-up. The trials also resulted in the re-design of a shotcrete gun to allow introduction of INORBOND liquid to INORBOND solid at the nozzle. Optimum results for shotcreting were attained using this method.

8) Earlier work showed that the iron hydroxide sludge from the lime treatment facility could be successfully solidified by a geopolymeric binder. To our knowledge, leach tests were not performed on the samples.

9) Compressive strength tests (Table 5b, sample 4-7-2) on shotcreted cylinders by Golder Associates show that strengths of 13.7 MPa were reached in three days. Strength continued to increase to 33.6 MPa, after a curing period of 31 days.

10) Lower 31-day strengths (9.4 MPa) were achieved by a sample (4-7-2a) from a similar mix poured on the same day as the tested shocrete cylinders. In this case, water was added.

5.2 PHASE 2 WORK

5.2.1 FREEZE-THAW TESTING

The measured data for freeze-thaw testwork are summarized in Table 10 (Sec. 4.2.1). From this data, the changes in physical parameters of the prisms are calculated. Table 11 summarizes this data.

Calculations of the dynamic modulus of elasticity and the durability factor for each prism after 300 cycles of freezing and thawing are shown in Table 12.

TABLE 12. MODULUS OF ELASTICITY AND DURABILITY FACTORS AFTER 300 CYCLES

PRISM	MODULUS OF ELASTICITY (MPa)			PERCENT CHANGE	RELATIVE DYNAMIC	DURABILITY FACTOR (%)
CYCLES	0	150	300	300	MODULUS OF ELASTICITY (%)	
COM-1	16275	16065	15720	-3.4	99	99
COM-2	16130	15850	15720	-2.5	99	99
F2-1	17300	16750	17240	-0.3	104	104
F2-2	15375	14550	12550	-18.4	88	88
F2-3	14825	15150	12550	-15.3	85	85

TABLE 11. CALCULATED DATA FOR THE FREEZE THAW PRISMS

A. ABSOLUTE VARIATIONS

CYCLES	WEIGHT (kg) 150	300	LENGTH (mm) 150	300	FREQUENCY (Hz) 150	300	VELOCITY ($m\ s^{-1}$) 150	300
PRISM								
COM-1	-0.074	-0.120	+0.065	+0.086	+4	-20	+49	+49
COM-2	-0.034	-0.073	+0.055	+0.065	-22	-26	+38	+38
F2-1	-0.134	-0.240	+0.283	+0.303	-15	+65	-3	+27
F2-2	-0.329	-0.427	+0.085	+0.099	0	-224	-15	-52
F2-3	0.013	-0.050	+0.534	+0.604	-55	-265	+483	+54

B. PERCENTAGE CHANGES

# OF CYCLES	WEIGHT 150	300	LENGTH 150	300	FREQUENCY 150	300	VELOCITY 150	300
PRISM								
COM-1	-1.22	-1.97	0.02	0.02	0.1	-0.5	0	-1.51
COM-2	-0.58	-1.24	0.02	0.02	-0.6	-0.7	1.18	1.18
F2-1	-2.06	-3.68	0.08	0.08	-0.4	1.8	2.88	0.80
F2-2	-5.20	-6.75	0.02	0.03	0	-6.4	-3.21	-4.25
F2-3	+0.20	-0.77	0.15	0.17	-0.1	-7.8	17.13	19.37

90-day flexural testing on 2 prisms from the COM series of prisms returned values of 3.4 and 4.0 MPa. In addition, a 90-day compressive stress test performed on a "F" series prism returned values of 30.9 and 30.0 MPa for two cubes cut from the prism.

5.2.2 PHASE 2 SHOTCRETE TRIALS

As noted in Sec. 4.2.2, surface solidification times ranged from 1.5 to 5 minutes. No slump was noted to occur. No surficial cracking of the material was observed. Coring of a section of structural roadway using a compressed air driven hand drilling apparatus was performed 24 hours after the shotcrete was laid down. It was found that coring of the material was extremely difficult due to the hardness of the material. After 2 hours of labour, 6 cores ranging from 5 to 9 cm. in length were obtained. Two of the cores were submitted for compressive stress testing. The 48-hour strength obtained for the cores was 36.8 and 34.5 MPa respectively.

6.0 DISCUSSION

The field trials conducted prior to and during the Phase I program provided some interesting information. It was shown during the Hope Brook work that conventional mixing technology (i.e., a standard cement truck) could be used to assist in the application of the binder. This application also showed that exposure of the cement to running water a few hours after application had no discernable effect. The field scale pour trial with a geopolymeric cement showed that a mix could be successfully used at temperatures of 50 ^{o}F, and cylinders taken during the pour showed increasing compressive strengths up to 33 MPa over one month. The first shotcreting trials provided dramatic information, demonstrating that the binder sets extremely rapidly, and with minimal amounts of binder liquid portion, when applied under high pressure.

Although no leach tests were conducted on the iron hydroxide sludge, it is worth noting that the sludge was successfully solidified. This area could be a focus of future work.

Testwork conducted in Phase I with various fillers, activators and aggregates provided information which could be useful for developing mixes for specialized applications. Fly ash did not prove to be as valuable as aniticipated, as it seems to create a significant loss in strength and also require higher amounts of binder. Silica fume contributes to ease of mixing, which can be valuable, and clay provides increased moldability. Proportions of water in the mix proved to be critical; the addition of a few percent too much water can have disastrous effects on strength.

Compressive strength tests were conducted on a number of hand-sized cylinders after curing periods of 2 days. It should be noted that Golders Associates cautions that the true strengths of samples from these non-standard cylinders may be different than those reported. In response to this concern, two cylinders, one hand sized (2-7-2) and another a 4x8-inch standard cylinder (2-7-2a), both created from the same mix design, were compared. The strength for the large cylinder was over twice the strength obtained for the hand cylinder, suggesting that our reported strengths for this series may be considerably less than actual strengths. A chart of length:diameter ratios for the small cylinders indicated that minor variation in ratios had no effect on strength. Thus the strengths of the hand sized-cylinders have only been used for comparison with each other, rather than for comparison with "real world" situations.

Included among the conclusions which can be reached from the strength testing was that fly ash added at the expense of binder of course resulted in some loss of strength; strength loss was greater when ash was added at the expense of geopolymer powder than at the expense of liquid.

There is a wide variability in the results obtained from freeze-thaw testing of the Phase 2 prisms composed of INORBOND, conventional aggregates, and concrete additives. The measured variations appear both when comparing temporal and final results obtained for all prisms tested and when reviewing data relevant to individual prisms. The most uniform physical data sets for the prisms include the COM-1 and COM-2 prisms. All prisms tested underwent surface scaling ranging from moderate to severe (Carette, 1990).

A possible explanation of the widely variable temporal physical changes observed for the different prisms is that the prisms had not completely cured at the initiation of freeze-thaw testing. In support of this, the data presented in Table 9 (Sec 2.3.1) shows the dates of preparation of the various prisms. Assuming that testwork commenced within one week of submission to CANMET, the final three prisms poured had not completed a standard 28-day cure period prior to the commencement of freeze-thaw testwork. It is therefore probable that the prisms were still undergoing curing at the time of testwork. Accordingly, the prisms returning the most uniform physical data (COM-1, COM-2) represent those that had undergone a standard 28-day cure period. The temporal variations of physical properties for the individual prisms are shown in Figure 7.

Contradictory test results obtained from the temporal measurement of longitudinal frequency variations are emphasized with the COM-1 and F2-1 prisms. In addition, the measured temporal increase in pulse velocity for the COM-2 and F2-3 prisms also appears unusual.

Survival of the INORBOND prisms created for the purpose of the Halifax International Airport study indicate the material has acceptable durability. Additionally, the fast preliminary cure and final set times observed for both shotcreted material and prism pouring are considered valuable assets for ensuring that the application of the material to surfaces of varying orientations is successful.

The freeze thaw results of the Inorbond prisms compared to the results obtained by Malhotra and Giaccio (1987) are favourable. Figures 8-11 are comparison graphs of the physical changes for the INORBOND prisms relative to the prisms created for the Malhotra and Giaccio (1987) study. Similar percentage variations with respect to length change, velocity change, frequency change, and weight change are noted, in all cases, for 3 out of the 5 INORBOND prisms tested. The condition of surface scaling for freeze-thaw tested prisms was also noted by Malhotra and Giaccio (1987).

The ability for INORBOND to be applied using a shotcrete machine was demonstrated in both the first and second phases of the testing program. Plates 1-4 (Sec 2.3.2) illustrate the application of INORBOND with a shotcrete gun to a section of structural road surface and the resultant texture of the material following application. The high compressive strengths

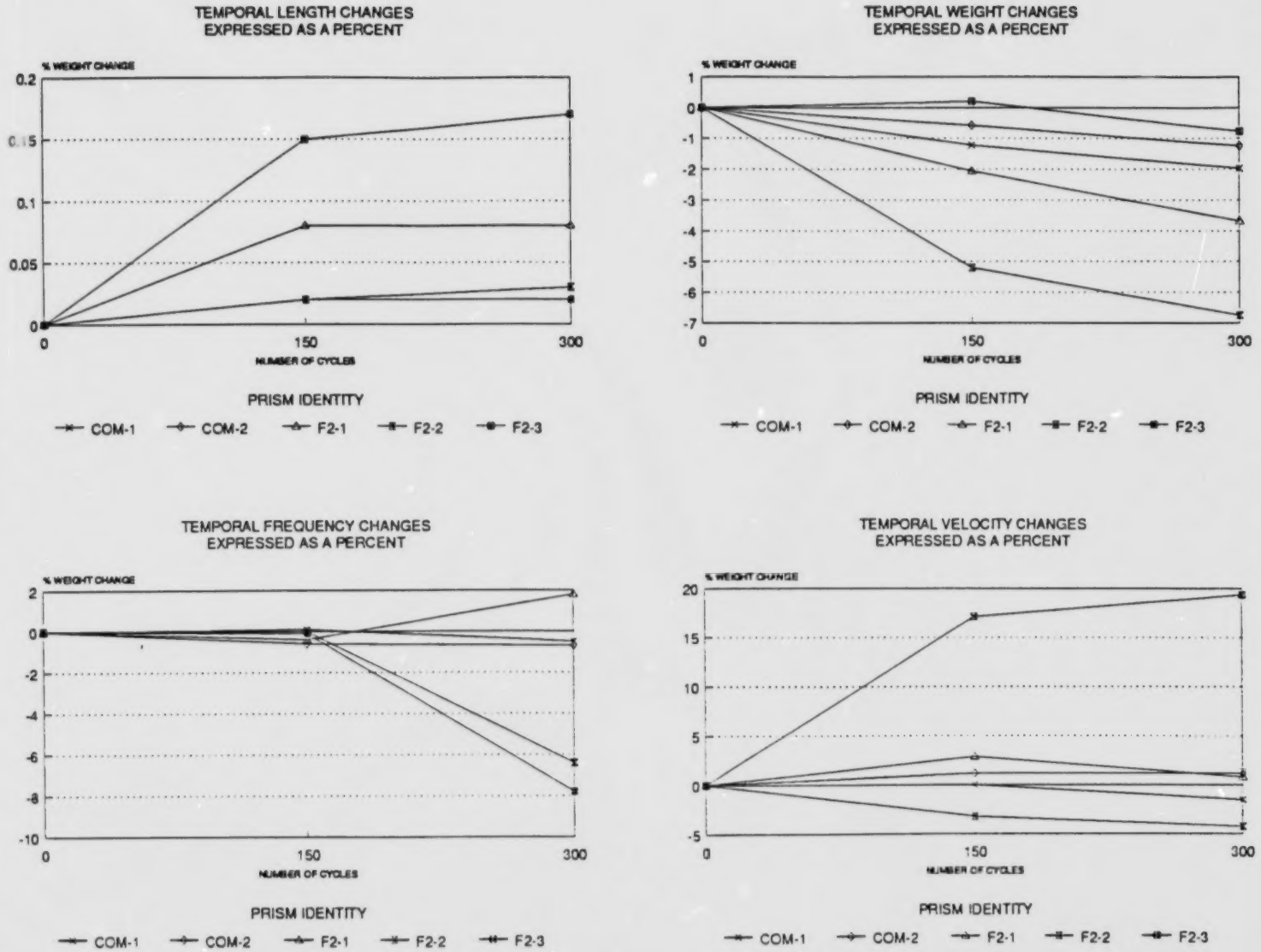
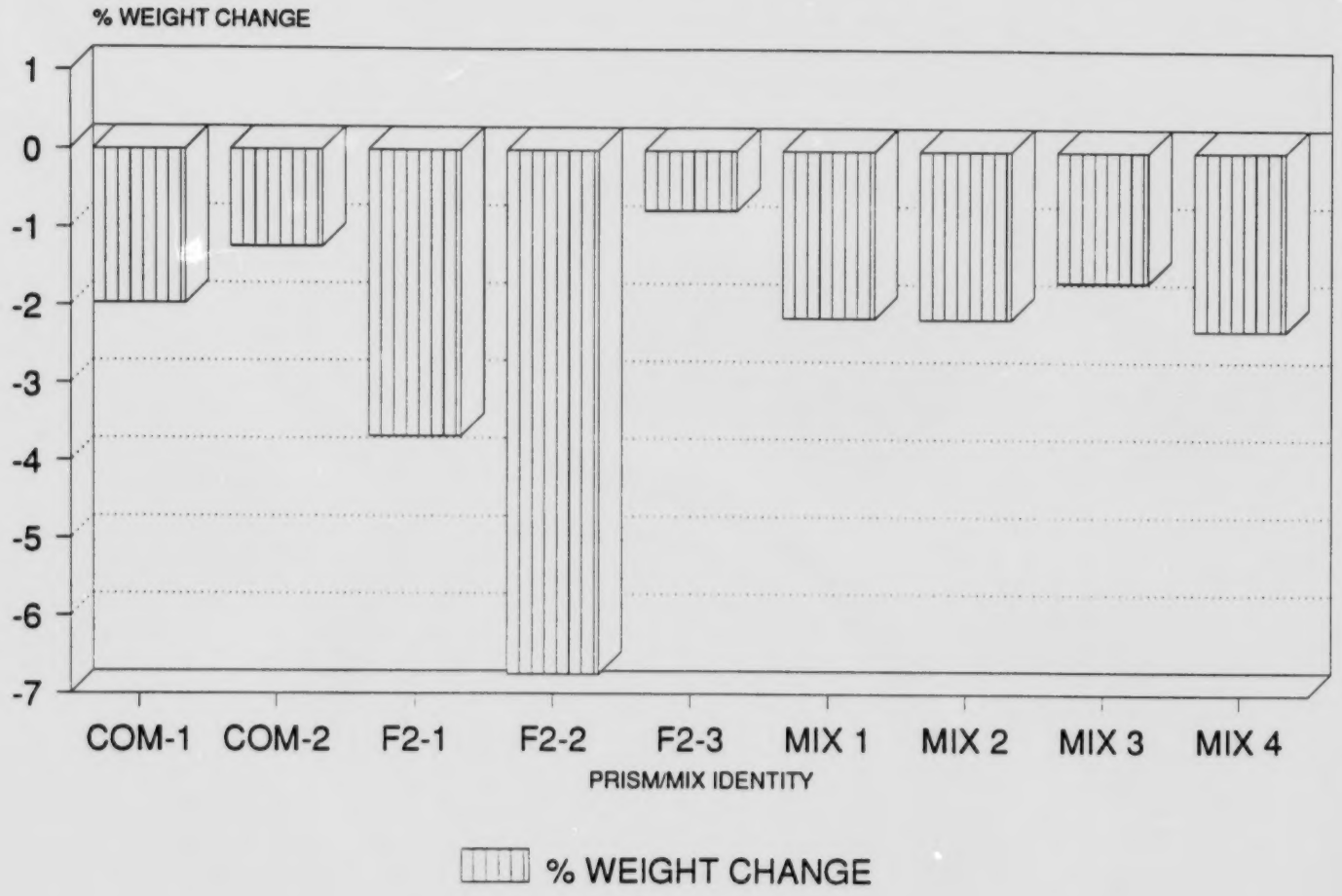


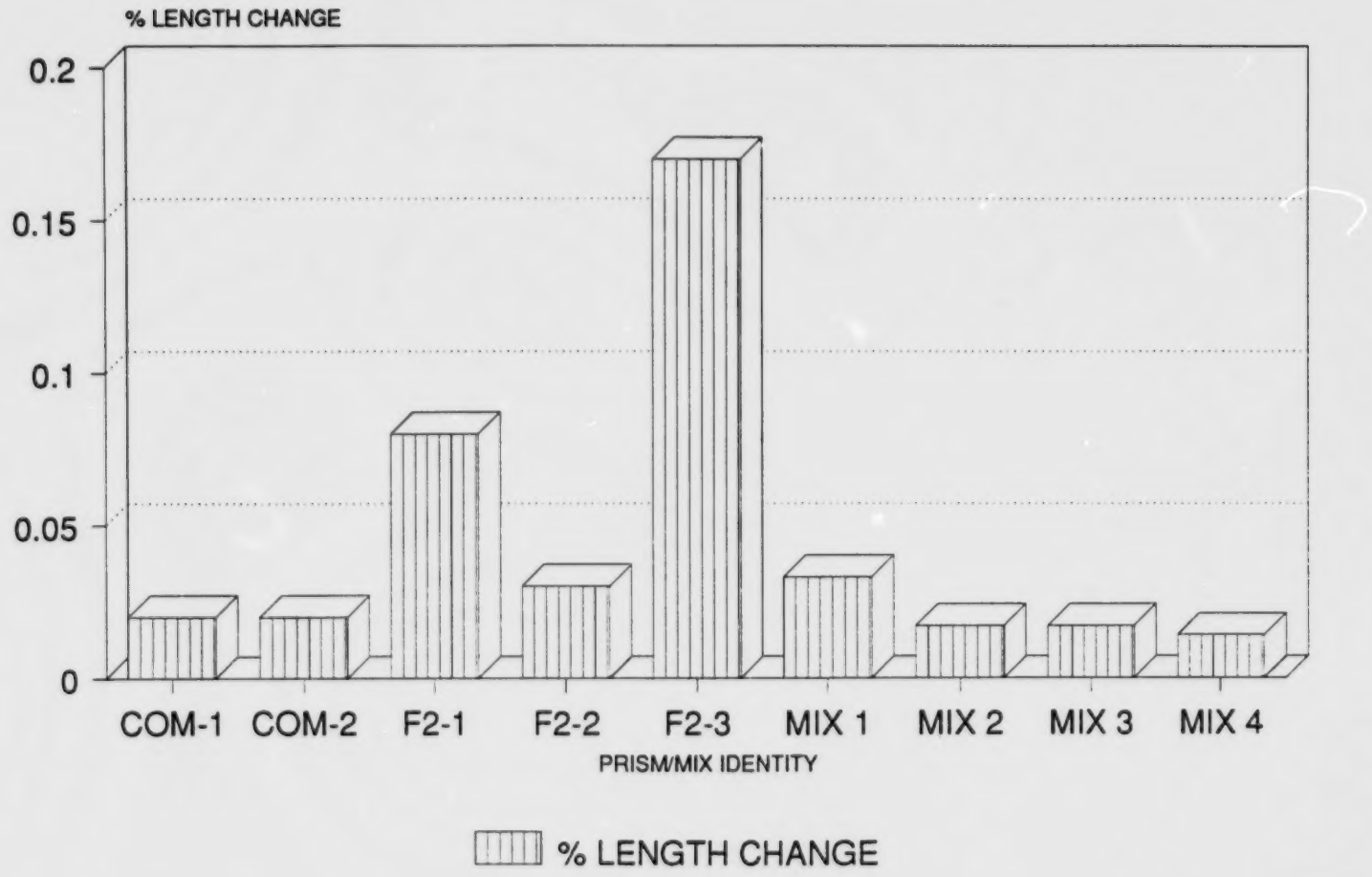
FIGURE 7. COMPARISON OF DATA FOR INORBOND PRISMS

FIGURE 8. % WEIGHT CHANGE
AFTER 300 CYCLES



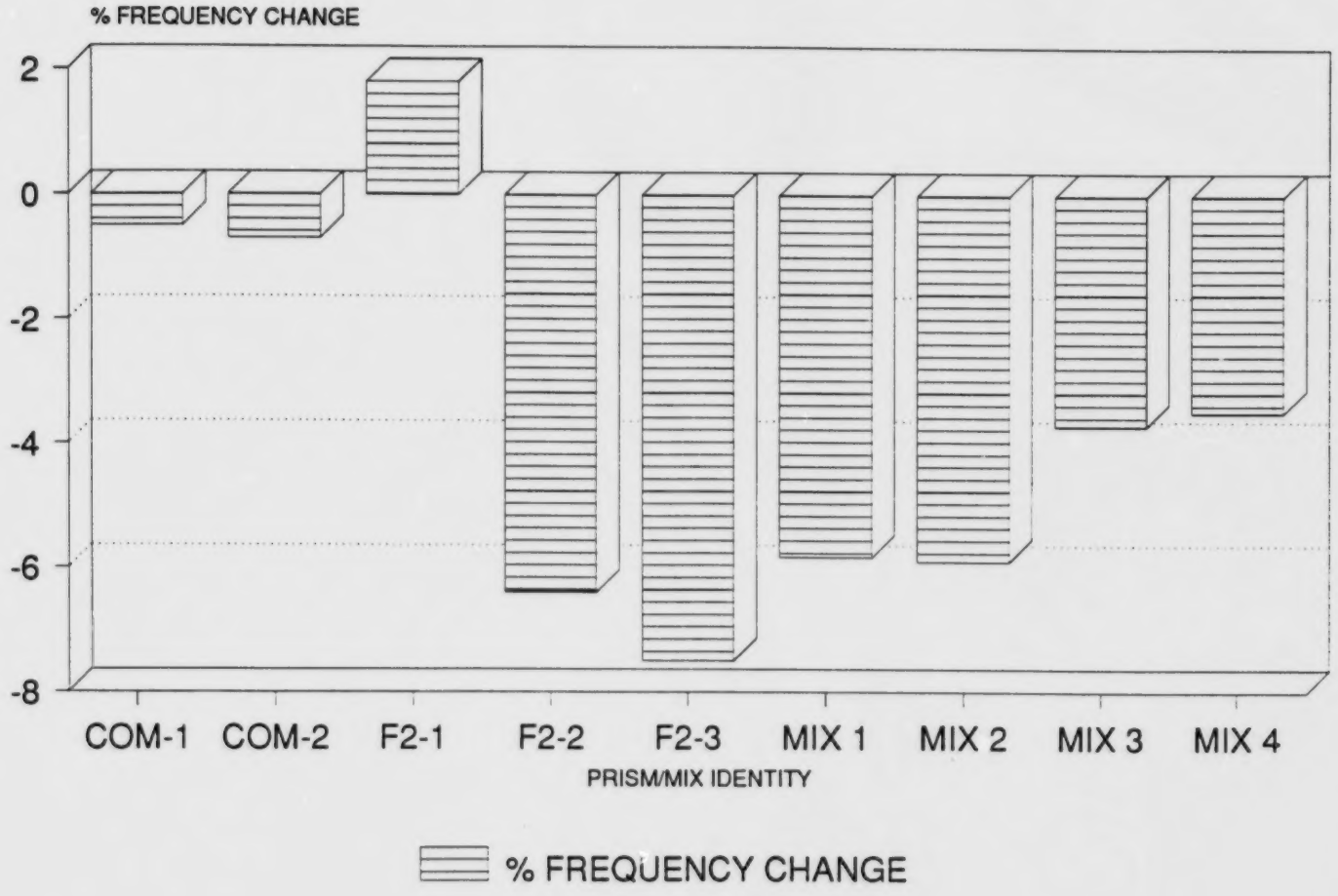
MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 9. % LENGTH CHANGE
AFTER 300 CYCLES



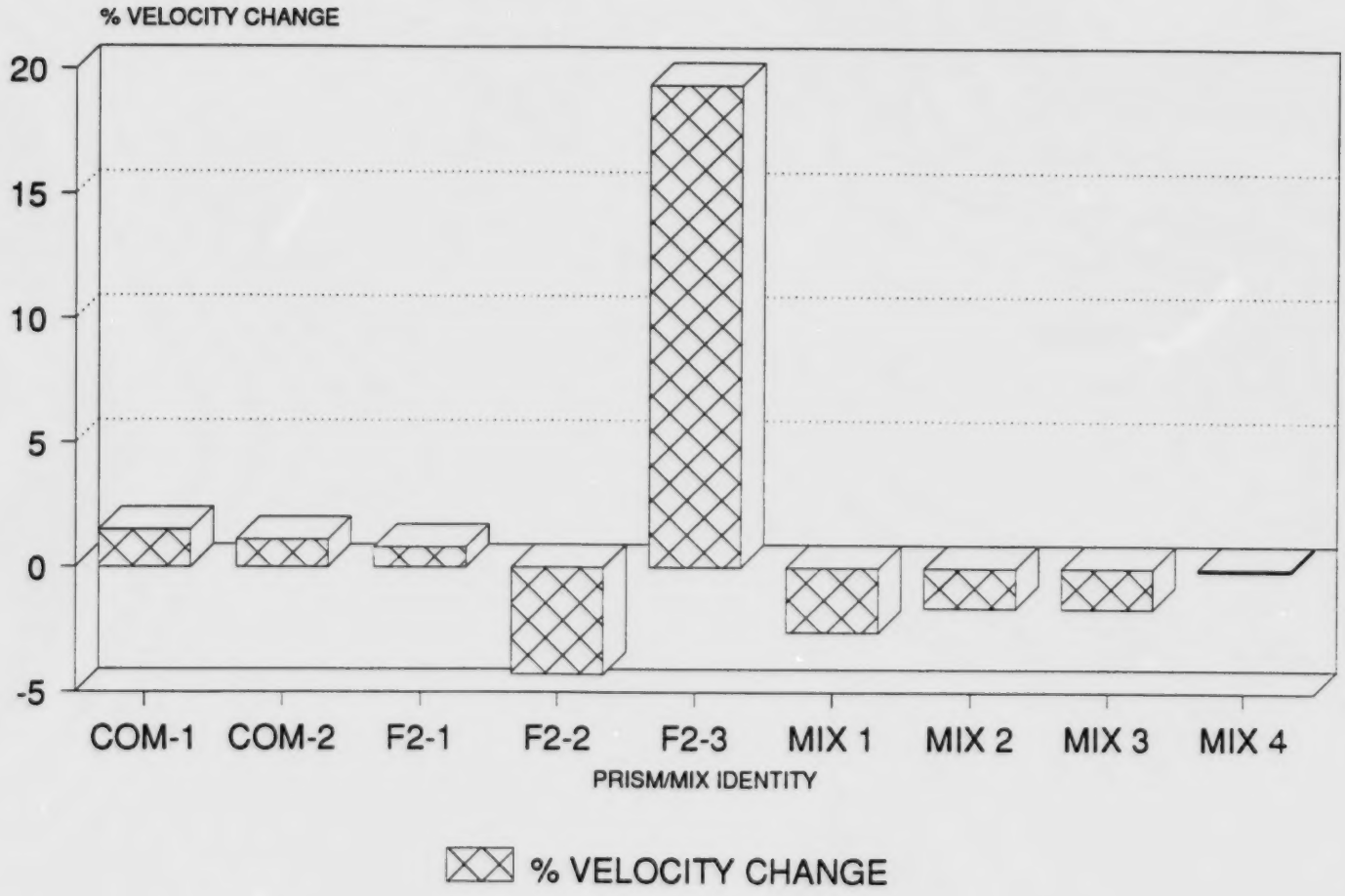
MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 10. % FREQUENCY CHANGE
AFTER 300 CYCLES



MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

FIGURE 11. % VELOCITY CHANGE
AFTER 300 CYCLES



MIX 1-4 AFTER MALHOTRA AND GIACCIO 1987

obtained 48 hours after shotcreting support the fast preliminary cure times noted during the program and suggest that the material may have additional applications in areas requiring minimal service interruptions.

6.1 COST ANALYSIS

Assuming that INORBOND is utilised as a shotcrete product to cap the outcroppings of pyritic slate at Halifax International Airport, the following analysis is designed to examine the costs associated with a large-scale rehabilitation to complete the project.

6.1.1 ASSUMPTIONS

i) Inorganic Binders: IB700 (solid), IB7822 (liquid)
ii) Aggregate: Nominal -6mm pea gravel and sand
iii) Application: Modified Shotcrete feed
iv) Mean Thickness: 0.10 metres
v) $IB_{(s)}$:Aggregate Ratio: 1:4
v) Final Product Delivery Specifications: Pre-mixed solid binder and aggregate shipped in supersacks with a 0.63 m^3 capacity. Product supply is F.O.B. Milton, Ontario, Canada. Liquid supply in drums or pails as necessary.

6.1.2 ANALYSIS

A. BINDER SUPPLY COSTS (ALL COSTS PER M^3)

MATERIAL	QUANTITY	COST
Inorbond 700	0.20 m^3	$100.00
Inorbond 7822	0.10 m^3	$128.00
Nominal -6 mm Aggregate	0.80 m^3	$ 32.00
Blending	1.00 m^3	$ 50.00
Packaging Solids	1.00 m^3	$ 56.00
Packaging Liquids	0.10 m^3	$ 25.00
TOTAL PRODUCT SUPPLY		$391.00

At a mean application thickness of 0.10 metres, the quantity of material detailed above would be sufficient to cover 10 m^2 of outcrop area. This cost translates to a cost per m^2 of $39.10. On a per ft^2 basis, the cost is $3.63.

B. CAPITAL EQUIPMENT REQUIREMENTS

Specific capital and consumable equipment requirements for the completion of the project include those items required for efficient application of the shotcrete materials. Experiences with shotcreting equipment in Phase 2 of the program outlined deficiencies in delivery of materials that are attributed to somewhat obsolete equipment.

ITEM	QUANTITY	UNIT COST	TOTAL COST
R-1 Shotcrete Machine	1	$15,000.00	$15,000.00
Vortex Nozzle	2	$ 200.00	$ 400.00
Radial Liquid Feed	2	$ 500.00	$ 1,000.00
Sandpiper Pump	1	$ 1,000.00	$ 1,000.00
Nozzle Inserts	10	$ 25.00	$ 250.00
0.25 X 10 m Piping	3	$ 100.00	$ 300.00
TOTAL SPECIAL CAPITAL EQUIPMENT COSTS			$17,950.00

The unit application cost of this equipment (for amortization purposes) will decrease as area of coverage is increased.

7.0 REFERENCES

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Results of freeze-thaw testing of prisms submitted to CANMET, fax communication, September 7, 1990. 9 pages.

D. Comrie Consulting Ltd., 1988:

Report on Field Work - Hope Brook Drainage Ditch. DCCL Internal Report, July 1988. 6 pages, and plates, appendices.

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APPENDIX 1. SUPPLY AND SERVICES CANADA CONTRACT

Supply and Services Canada | Approvisionnements et Services Canada

Supply and Services Canada
Science Branch
11C1 Phase III
Place du Portage
Hull, Quebec K1A 0S5

CONTRACT - CONTRAT

You are requested to sell to Her Majesty the Queen in right of Canada, in accordance with the terms and conditions set out herein, referred to herein or attached hereto, the services listed herein and on any attached sheets at the price or prices set out therefor.

Nous vous demandons de vendre à Sa Majesté la Reine du chef du Canada, aux conditions énoncées ou incluses par référence dans les présentes et aux annexes ci-jointes, les services énumérés dans les présentes et sur toute feuille ci-annexée, au(x) prix indiqué(s).

TITLE

TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

The vendor hereby accepts this contract - Le fournisseur accepte le présent contrat

Name, title of person authorized to sign (type or print)
Nom et titre du signataire autorisé (caractère d'impression) Signature Date

DELIVERY DATE:

May 15, 1989

Return signed copy forthwith - Prière de retourner une copie dûment signée immédiatement

D. COMRIE CONSULTANTS LTD. @42K19
120 TRADERS BLVD. EAST
SUITE 209
MISSISSAUGA, ONTARIO
L4Z 2H7 TEL: (416) 890-6500
ATTN: D. COMRIE

SSC file No. - N° de référence d'ASC
039SQ.23440-8-9171

Date of Contract - Date du contrat
22 Dec/déc 1988

Contract No. - N° du contrat
23440-8-9171/01-SQ

Requisition No. - N° de la demande

Order office Bureau demandeur	Yr An	Serial No. N° de série
23440	8	9171

Financial Code(s) - Code(s) financier(s)
234-131-000000-303701-0433

Duty - Droits
Included
Compris

F.O.B. - F.A.B.
Destination

Federal Sales Tax - Taxe de vente fédérale
Included
Compris

Destination
DEPT.ENERGY, MINES & RESOURCES
CANMET - MSL DIVISION
555 BOOTH STREET
OTTAWA, ONT. K1A 0G1
ATTN: MALHOTRA V.M.

Invoices - original and two copies are to be made out and sent to:
Factures - remplir et envoyer l'original et deux copies à:
DEPT.ENERGY, MINES & RESOURCES
CANMET - CONTRACTS OFFICE
555 BOOTH STREET
OTTAWA, ONT. K1A 0G1
ATTN: S. RISTOW

Address enquiries to: - Adresser toute demande de renseignements à:
D. Lamoureux

Area code code régional	Telephone No. N° de téléphone	Extension Poste	Telex No. N° de télex
819	956-1342		053-3703

Total est. cost - Coût total est.
$39,564.00

For the Minister - Pour le Ministre
Lalonde

Canada

DSS-MAS 9400-10 (10/86)

TITLE

TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

STATEMENT OF WORK

The Contractor shall carry out the work in accordance with the Statement of Work attached hereto as Appendix "A" and forming part of this contract.

The work will be performed in accordance with the methodology of the contractor's technical proposal entitled, "To Develop Geopolymer Formulations and to Determine Their Mechanical and Durability Properties for Capping of Pyritic Slate Outcrops at Halifax Airport" dated December 15, 1988.

PRIORITY OF DOCUMENTS

The documents listed below form part of and are incorporated into this Contract. If there is a discrepancy between the wording of one document from the wording of any other document which appears on the list, the wording of the document which first appears on the list shall prevail over the wording of any document which subsequently appears on the list:

1. these articles of agreement
2. Statement of Work, Appendix "A"
3. General Conditions Research and Development DSS 9224
4. Basis of Payment, Appendix "B"
5. Contract Plan and Report Form, App. "C"
6. Claim for Progress Payment Form DSS 1111
7. Disclosure Certification, Appendix "F"
8. Cost Submission, Appendix "E"
9. Invoicing Instructions, Appendix "D"
10. Title Page, Appendix "G"
11. Contractor's proposal identified on page 1

MEETINGS

Technical review meetings are to be held if and when considered necessary by the Scientific Authority, at a time and place specified by him.

CONTRACT PLAN AND REPORT FORM

The Contract Plan and Report Form (DSS 9143-3) completed and attached herewith as Appendix "C" forms part of the contract. This form, completed in accordance with the instructions provided in DSS 9143 and 9143-2, must accompany each claim for payment. Receipt and acceptance of the form by the Science Branch Contracting Officer will be a condition of payment for such claims. The Contract Plan and Report Form will provide the basis for measuring the progress of the work and the Contractor's performance under this contract.

MONTHLY PROGRESS REPORTS

You shall prepare and submit progress reports as specified in the "Deliverables" clause.

Each progress report shall be in three (3) parts:

Part 1: The following three questions MUST be answered:

1. Is the project on schedule?
2. Is the project on budget?
3. Is the project free of any areas of concern on which Crown assistance or guidance may be required?

Each negative response must be supported with an explanation.

Part 2: A narrative report, brief, yet sufficiently detailed to enable the Scientific Authority to evaluate the progress of the work, containing as a minimum:

1. A description of the progress of each task and of the work as a whole during the period of the report. Sufficient sketches, diagrams, photographs, etc., shall be included, as necessary to describe the progress accomplished.

2. An explanation of any variation from the plan of work.

3. A description of trips or conferences connected with the contract during the period of the report.

Part 3: The Contract Plan and Report Form, DSS 9143-3, showing the following:

1. actual and forecast expenditure on a monthly basis for the period of work being covered. (Expenditures are to be outlined by month and by task.)

2. progress of the work against your original Contract Plan (instructions for showing the above on the Contract Plan and Report Form attached hereto).

DRAFT AND FINAL REPORT

A copy of the Final Report, in a draft form, as close as reasonably possible to the Final Report itself, is to be submitted for review and comments by the Scientific Authority. Implementation of modifications and editorial changes requested by the Scientific Authority will normally result in the Final Report.

FINAL REPORT

The Final Report must be a comprehensive report on all facets of the work and must include sufficient drawings, sketches, photographs and discussion of problems and successes associated with the work to facilitate a full and accurate evaluation of the work by the Scientific Authority. The report will be prepared in accordance with good engineering practices and will include, as a minimum, the following: title page, list of contents, summary introduction, technical discussion, conclusions and supporting graphs, tables and figures, as applicable.

The Final Report must contain an executive summary in both English and French. The Final Report will also contain a Title Page. The Title Page is attached as Appendix "F" to this Contract.

DELIVERABLES

Deliverable Item	Delivery Date	Scientific Authority	Science Branch Contracting Officer
Claim	Monthly		Original + 4
Progress Report	Monthly	1	1
Draft Report	May 1, 1989	1	Transmittal Advice
Final Report	May 15, 1989	Orig. + 6	" "
Holdback Claim	" "		Orig. + 4
Disclosure Cert.	" "	1	1
Cost Submission	" "		1

SCIENCE BRANCH CONTRACTING OFFICER

Mrs. Diane Lamoureux
Senior Purchasing Assistant
Science and Professional Services Directorate
Department of Supply and Services Canada
Place du Portage, Phase III, 11C1
11 Laurier Street
Hull, Quebec
K1A 0S5

TELEPHONE: (819) 956-1342
FAX: (819) 997-2229
TELEX: 053-3703

The Science Branch Contracting Officer is responsible for the management of this Contract and any changes to the contract must be authorized by a formal contract amendment issued by that Officer. The Contractor is not to perform work in excess of or outside the scope of this contract based on verbal or written requests or instructions from any government personnel other than the aforementioned officer.

SCIENTIFIC AUTHORITY

Mr. V.M. Malhotra
Energy, Mines and Resources
CANMET, MSL Division
555 Booth Street
Ottawa, Ontario
K1A 0G1

TELEPHONE: (613) 996-5449

The Scientific Authority is reponsible for all matters concerning the scientific and technological content of the work under this contract. Any proposed changes to the scope of the work are to be discussed with the Scientific Authority, but any resultant changes can only be authorized by a contract amendment issued by the Science Branch Contracting Officer.

BASIS OF PAYMENT

The Contractor will be paid its costs reasonably and properly incurred in the performance of the work, in accordance with Appendix "B" attached hereto and forming part of this Contract.

METHOD OF PAYMENT

Monthly progress payments will be made up to 90% of the amounts reasonably and properly incurred in accordance with the Basis of Payment, provided:

(a) the Contractor submits a fully completed claim for progress payment on form DSS 1111, detailed in accordance with the items of the Basis of Payment and showing applicable holdback;

(b) all of the certificates appearing on the said form are signed by the respective persons indicated thereon or their delegate; and

(c) each claim is supported by two full sets of documentation (receipts, invoices, etc.) to support all charges made against the contract, to the satisfaction of the Science Branch Contracting Officer;

(d) a satisfactory progress report including the updated Contract Plan and Report Form is received and accepted.

Claims shall be routed in accordance with the invoicing instructions in Appendix "D" of this contract.

The holdback should be claimed separately on Form DSS 1111 in the same manner described above and will be paid upon:

(e) receipt and acceptance of all deliverables;

(f) receipt of the Contractor's final claim and cost submission;

(g) receipt of a disclosure certification (see Intellectual and Industrial Property clause).

Payment by Her Majesty to the Contractor for the work shall be made:

(h) in the case of a progress payment other than the final payment, within thirty (30) days following the date of receipt of a duly completed progress claim, form DSS 1111;

(i) in the case of a final payment, within thirty (30) days following the date of receipt of a duly completed final progress claim, form DSS 1111, or within thirty (30) days following the date on which the work is completed, whichever date is the later;

(j) if Her Majesty has any objection to the form of the progress claim, within fifteen (15) days of its receipt, She shall notify the Contractor of the nature of the objection. "Form of the progress claim" means a claim which contains or is accompanied by such substantiating

documentation as Her Majesty requires. Failure by Her Majesty to act within 15 days will only result in the date specified in paragraphs (a) and (b) above to apply for the sole purpose of calculating interest on overdue accounts.

INTEREST ON OVERDUE ACCOUNTS

(a) (i) In this Article an amount is "due and payable" when it is due and payable by Her Majesty to the Contractor according to the terms of the contract.

(ii) For the purposes of this Article, an amount is overdue when it is unpaid on the first day following the day upon which it is due and payable.

(iii) In this Article "date of payment" means the day prior to the date of the negotiable instrument drawn by the Receiver General for Canada and given for payment of an amount due and payable.

(iv) In this Article "Bank Rate" means the discount rate of interest set by the Bank of Canada.

(b) (i) Her Majesty shall be liable to pay, without demand from the Contractor, simple interest at the Bank Rate plus 1 1/4 per centum on any amount which is overdue from the day such amount became overdue until the day prior to the date of payment, inclusively; interest will not be payable nor paid unless the amount has been outstanding (unpaid) for more than 15 days following the due date. Interest will not be payable on overdue advance payments.

(ii) The Bank Rate shall be that prevailing at the opening of business on the date of payment.

(c) Interest shall only be paid when Her Majesty is responsible for the delay in paying the Contractor. In the event Her Majesty is not responsible for the delay in paying the Contractor, no interest shall be paid.

CONDITIONS PRECEDENT TO PAYMENT

No payment shall be made to the Contractor unless or until:

a) invoices, inspection notes and all other documents prescribed from time to time by the Minister or inspector are submitted in accordance with the terms of the contract or instructions of the Minister;

b) with respect to all materials, parts, work in process or finished work, the cost of which has been paid by the Contractor and in respect of which payment is being made by the Minister, the Contractor, if required to do so, establishes to the satisfaction of the Minister that the materials, parts, work in process or finished work are free from all claims, liens, attachments, charges or encumbrances;

c) with respect to all materials, parts, work in process or finished work, the costs of which have accrued in the accounts of the Contractor as a liability to be discharged in the normal course of business and in respect of which materials, parts, work in process or finished work payment is being made by the Minister, the Contractor, if required to do so, establishes to the satisfaction of the Minister that it is not, in the ordinary course of business, delinquent in discharging its accrued liabilities arising from the performance of the contract and that the payment to be made by the Minister shall be used only for the purpose of discharging such liability and that upon such discharge the materials, parts, work in process or finished work shall be free from all claims, liens, charges or encumbrances; and

d) in the case of payment in respect of finished work, such finished work has been inspected and accepted in accordance with the terms of this Contract.

PROVINCIAL AD VALOREM

The following clause replaces Item 1 under B. Conditions on the reverse side of page 1:

Excluding the exceptions noted below, the Contractor shall not invoice or collect any ad valorem sales tax levied by the province in which the goods or taxable services are delivered to federal government departments and agencies under authority of the following provincial sales tax licences:

Newfoundland	32243-0-09
Prince Edward Island	OP-10000-250
Nova Scotia	U84-00-03172-3
New Brunswick	P87-60-01648
Quebec	Q-398-SS-3921-1-P
Ontario	11708174G
Manitoba	390516-0
British Columbia	005521

Exceptions

(a) Petroleum products subject to provincial gasoline and motor fuel taxes
(b) Tobacco products
(c) Prepared meals and transient living accommodations
(d) Broadcast advertising services (Quebec/Newfoundland) and all other advertising in Newfoundland
(e) Amusement and/or entertainment taxes

In Alberta and Saskatchewan, provincial retail sales taxes do not apply to goods or taxable services delivered to the federal government under this contract.

THE CONTRACTOR IS NOT RELIEVED OF ANY OBLIGATION TO PAY PROVINCIAL SALES TAXES ON GOODS OR TAXABLE SERVICES USED OR CONSUMED IN THE PERFORMANCE OF THIS CONTRACT, INCLUDING MATERIALS INCORPORATED IN REAL PROPERTY.

LIMITATION OF EXPENDITURE

Her Majesty's liability to the Contractor shall not exceed $39,564.00 inclusive of Federal Sales Tax, where exigible and paid by the Contractor, unless otherwise authorized in writing by the Science Branch Contracting Officer. The Contractor shall not be obliged to perform any work or provide any service that

would cause the total liability of Her Majesty to exceed the said sum, unless an increase is so authorized. The Contractor shall notify this Department as to the adequacy of this sum when it is 75% committed. If the notification refers to inadequate funds, then the Contractor shall, at the same time, provide a new estimate of the total cost of the work. Notwithstanding the aforegoing, the Contractotr shall notify this Department and provide a new estimate of cost if at any time the Contractor considers the funds provided are inadequate for the completion of the work. The giving of such notification and estimates shall not increase her Majesty's liability over the Limitation of Expenditure listed above.

The Contractor shall not adopt any change or changes in the work that would cause an increase in the cost of the work, until the Contractor receives written authorization from the Science Branch Contracting Officer. Costs incurred without such authorization shall not be reimbursed by Her Majesty.

COST SUBMISSION

Upon completion of the contract the Contractor shall prepare and submit a Cost Submission to the Science Branch Contracting Officer designated herein. The Cost Submission shall be a statement of the costs incurred by the Contractor in accordance with the Basis of Payment, for the work performed under the terms of the contract.

The Cost Submission shall be signed and certified by the Contractor's Senior financial officer and shall contain a breakdown of each element of cost.

Supporting information for each element of cost shall be available and shall be in sufficient detail that an in-depth audit can be carried out (see Appendix "E").

DISCRETIONARY AUDIT

The following are subject to Government audit before or after payment is made:

(a) Amounts claimed under the terms and conditions of the contract as computed in accordance with the Basis of Payment including time charged, and salaries paid for labour charges based on salaries times a firm negotiated multiplier.

(b) The accuracy of the Contractor's time recording system.

(c) The estimated amount of profit in any firm priced element, firm time rate, firm overhead rate, or firm salary multiplier, for which the Contractor has provided the appropriate certification. The purpose of such audit would be to determine whether the aggregate of actual profit earned by the Contractor on a series of negotiated contracts containing one or more of the aforementioned prices, time rates or multipliers, and received during a particular period selected, is fair and reasonable based on the estimated amount of profit included in earlier certifications.

(d) Any firm priced element, firm time rate, firm overhead rate, or firm salary multiplier for which the Contractor has provided a "most favoured customer" certification. The purpose of such audit would be to determine whether the Contractor has charged anyone else, including the Contractors most favoured customer, lower prices, rates or multipliers, for like quality and quantity of goods or services.

Any payments made pending completion of the audit shall be regarded as interim payments only and shall be adjusted to the extent necessary to reflect the results of the audit. If there has been any overpayment it shall be promptly refunded to the Crown.

INTELLECTUAL AND INDUSTRIAL PROPERTY

Final payment under the contract will be made only after receipt by the Science Branch Contracting Officer and the Scientific Authority of a certification made by an officer of the Contractor, stating that all applicable disclosures were submitted or that there were no disclosures to submit. A copy of these certifications are attached as Appendix "F".

CONFLICT OF INTEREST

It is a term of this Contract that no former public office holder who is not in compliance with the post-employment provisions of the Conflict of Interest and Post-Employment Code for Public Office Holders shall derive a direct benefit from this Contract.

SOUTH AFRICAN CONDITION

(1) Subject to subsection (2), the Contractor shall ensure that, to its knowledge, the goods and services to be provided pursuant to this Contract are neither of South African origin nor obtained from a company that is majority-owned (51 percent of the voting rights) by South African interests.

(2) Where the Contractor is aware that goods or services of South African origin or obtained from companies that are majority-owned by South African interests are to be supplied in connection with this Contract, the Contractor shall in its response identify the items involved, the estimated total value of the goods and services, and the justification for their use.

(3) Following a review of the Contractor's justification, the Minister may accept or reject the justification, at the sole discretion of the Minister.

(4) Where the Minister rejects the Contractor's justification referred to in subsection (3), the Minister may terminate the contract in accordance with subsection (5).

(5) The Contractor agrees that the Minister relies upon subsections (1) and (2) to enter into this Contract and any breach of subsection (1) or (2) shall entitle the Minister to terminate this contract for default and to recover from the Contractor damages, including reprocurement costs arising out of such termination.

(6) The Contractor agrees to bind each first-tier Canadian-based subcontractor by the terms of this clause.

EXPIRY DATE

Notwithstanding the delivery date of the Final Report, this Contract will remain in effect until 90 days after the specified delivery date of the Final Report. During this 90 day time period, miscellaneous activity relating to contract close-out will occur.

Notwithstanding the above, no costs are to be incurred after the delivery date stipulated without written approval of the Science Branch Contracting Officer.

GENERAL CONDITIONS

In lieu of General Conditions DSS 9329 referred to in the reverse side of Page 1, the terms and conditions of General Conditions Research and Development DSS 9224 (8/84) as modified hereunder, shall apply to and form part of this Contract.

Modifications:

(i) Conduct of the Work: Part 2, Article 7 of the Terms and Conditions DSS 9224 is hereby supplemented by adding the following subsection:

(5) The Contractor shall not stop or suspend work pending the settlement or determination of any differences arising under the contract, unless so instructed by the Minister.

(ii) Subcontracts: Article 11 of the Terms and Conditions DSS 9224 is hereby supplemented by adding the following sentence to subsection 1:

For work requiring consent, should the Contractor propose to solicit bids from other than Canadian sources, the Contractor shall obtain the consent, in writing, of the Minister prior to solicitation.

(iii) Paragraph (b) of subsection 2 of Article 21 of Terms and Conditions DSS 9224 is deleted in its entirety and the following is substituted therefor:

b) the Work or any portion of the Work is terminated, the Contractor shall be paid for all finished deliverables delivered and accepted and for all materials or work-in-process delivered and acceptable to Her Majesty, the Cost to the Contractor in accordance with the terms of the contract plus the proportional part of any fee applicable thereto. The Contractor shall also be entitled to be reimbursed its costs which are incidental to the cancellation of obligations incurred by the Contractor pursuant to the termination notice, the cost of preparing the necessary accounts and statements with respect to the Work performed to the effective date of such termination and commitments made by the Contractor with respect to the terminated portion of the Work, wages which the Contractor is obliged under any laws or regulations for the time being in force, to pay employees whose services are no longer required by reason of such termination, the costs of and incidental to the taking of any inventory of materials, components, work-in-process and finished work on hand at the effective date of the termination and other costs and expenses of and incidental to the termination in whole or in part, of operations under the contract; provided always that payment and reimbursement under the provisions of the subsection shall be made only to the extent that is established to the satisfaction of the Minister that the said costs and expenses were actually incurred by the Contractor and that the same are reasonable and are properly attributable to the termination of the Work or the part thereof so terminated.

c) In no event shall the aggregate of the price paid to date and the amounts payable pursuant to this Article, exceed the total Contract Price.

d) The Contractor shall have no claim for damages, compensation, loss of profit, allowance or otherwise by reason of or directly or indirectly arising out of any action taken, or notice given by the Minister under or pursuant to the provisions of this Article except as and to the extent expressly provided."

APPENDIX "A"

14SQ.23440-8-9171

STATEMENT OF WORK

The contractor will develop geopolymers formulations for capping pyritic slate outcrops at Halifax International Airport. The formulations will be developed with a view of optimising the use of geopolymers and other mineral admixtures such as fly ash slag and silica fume. Data on mechanical properties such as compression, flexural and modulus of elasticity will be developed. Additional test specimens will be cast for determining the freezing and thawing resistance permeability and coefficient of thermal expansion of geopolymer systems, large panels will be shotcreted to test the applicability of the geopolymers using a shotcrete gun. The panels will be cored to determine the mechanical properties of the material. Data obtained in the above investigation will be analyzed as to determine the feasibility of using the geopolymer technology for capping the pyritic slate outcrops and cost estimates of doing such a job will be given.

APPENDIX "B"

39SQ.23440-8-9171

BASIS OF PAYMENT

LABOUR

At firm hourly rates inclusive of overhead and profit

	Estimated Days	Firm Hourly Rates	
Senior Project Leader	48	$88.00	
Technician 1	104	$59.00	
Technician 2	104	$43.00	
Secretary	8	$31.00	
Total Estimated Cost of Labour:			$15,080.00

EQUIPMENT

At laid down cost without mark-up $ 1,500.00

MATERIAL, SUPPLIES AND COMPONENTS

At laid down cost without mark-up $ 200.00

SUBCONTRACT

At laid down cost without mark-up $20,700.00

TRAVEL AND LIVING

At actual cost not to exceed Travel and Living Guidelines attached on the following page 2 $ 1,684.00

OTHER DIRECT CHARGES

At laid down cost without mark-up $ 400.00

TOTAL CONTRACT PRICE TO A LIMITATION OF EXPENDITURE: $39,564.00

TRAVEL AND LIVING GUIDELINES

MEALS

	ALL PROVINCES	YUKON AND N.W.T.	U.S.A.
Breakfast	$ 6.40	$ 8.20	$ 6.90
Lunch	$ 8.50	$10.10	$ 9.00
Dinner	$18.10	$21.20	$19.10
Total Daily Meal Allowances	$33.00	$39.50	$35.00

INCIDENTAL EXPENSES

You may claim up to $6.00 per full day (24 hours) in travel status when commercial accommodation is used and up to $4.00 when private accommodation is used.

SPECIAL TRAVEL SITUATIONS

When unusually high costs are incurred, such as during field reseach in the far north, actual expenses for incidentals and meals will be reimbursed, based on proof of payment, to the extent that the Minister considers the expenses claimed are reasonable and justifiable in the circumstances.

ACCOMMODATION

Single occupancy commercial accommodation of reasonable quality and comfortably equipped. LUXURY ACCOMMODATION IS NOT PERMITTED.

For private accommodation provided by friends or relatives: $13.50 (CDN) per night in Canada, and $13.50 (U.S.) per night in the U.S.A.

TRANSPORTATION

Intercity:

Intercity (air/rail/bus) transportation costs: use the most practical, economy class public transportation.

Private vehicle mileage reimbursement shall not exceed the most practical economy class, public transit fare. Use of private vehicles not authorized for travel destination in excess of 200 miles/320 km.

.../3

Mileage rates to a maximum of 4,000 miles or 6,500 km

N.S., N.B., P.E.I. & B.C.	Man., Sask. & Alta.	N.W.T. Yukon	Nfld.	Quebec	Ontario
46.5 /mile 29.0 /km	44.5 /mile 27.5 /km	56.5 /mile 35.0 /mile	49.0 /mile 30.5 /km	47.0 /mile 29.5 /km	47.0 /mile 30.5 /km

Local

Use public transit (airport buses, etc.) where applicable.

Rent compact economy cars unless the number of passengers or load justifies a larger vehicle. (Personal accident coverage is not allowable).

RECEIPTS AND VOUCHERS

A statement indicating the names of travellers, places visited and when, length of visits and purpose of travel, must be submitted with each claim for travel and living expenses.

Receipts and vouchers for accommodation and transportation may be required to be submitted with claim. No receipt or voucher is required for private accommodation.

ENTERTAINMENT IS NOT AN ALLOWABLE COST

(October 1, 1988)

Supply and Services Canada / Approvisionnements et Services Canada

DSS-MAS 9143-3 (4/81)

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT

CONTRACTOR – ENTREPRENEUR

FILE No. – N° DU DOSSIER	SERIAL No. – N° DE SÉRIE

TASK DESCRIPTION / DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COÛT DE LA TÂCHE		
	1 JAN	2 FEB	3 MAR	4 APRIL	5 MAY	6	7	8	9	10	11	12	PLANNED / PRÉVU À L'ORIGINE	ACTUAL / PRÉSENTEMENT	E.T.C. / À VENIR
DATA REVIEW	☐												1,560		
MIX DESIGN	☐												11,630		
PHYSICAL TESTING (I)		☐											14,300		
SITE EVALUATION		☐											1,974		
APPLICATION TRIALS		☐											4,220		
PHYSICAL TESTING (II)			☐	☐									5,600		
REPORT (FINAL)				☐									4,820		
PLANNED COST BY MONTH / COÛT PRÉVU POUR CHAQUE MOIS													PLAN 44,104		
ACT. PRESENT. / E.T.C. BY MONTH / PRÉVISION POUR CH. MOIS	13,190	20,414	2,800	7620										ACTUAL / COÛTS RÉELS	E.T.C. / À VENIR

Appendix "C"

DSS-MAS 9143 (8/81)

CONTRACT PLAN AND REPORT FORM

Instructions to Contractor

This form serves a dual purpose; the first is for planning and estimating the work, and the second is for reporting actual progress against the plan during contract execution.

PROPOSED PLAN

Your work and cost plan must be prepared on this "Contract Plan and Report Form" DSS-MAS 9143-3 and must be submitted as part of your proposal. The plan shall demonstrate how you propose to execute the contract by subdividing the work into tasks and providing for each task an estimate of the cost and a schedule for completion. An example of a completed form is attached, (page I).

Use additional pages if the number of tasks exceed 15, or if the contract duration will exceed 12 months. For high value contracts in excess of $1M you are required to subdivide the work into major tasks which in turn are to be subdivided into minor tasks, e.g. a system is divided into subsystems which in turn are divided into subtasks, such as subsystem components.

You will be required to revise your plan to reflect the results of the contract negotiation. The revised plan will form part of contract.

REPORTING PROGRESS

Following contract award, monthly progress reports which record actual start dates and projected completion dates by task, actual cost by task, actual cost by month, Estimate to Complete (E.T.C.) by task and E.T.C. by month are to be prepared and submitted in accordance with the attached example, (page II), unless otherwise noted in the contract.

NOTE: The contract file number, serial number and the actual months duration are to be entered in the appropriate blocks of the first and subsequent reports. The report period is to be indicated by drawing a solid vertical line at the end of the applicable month. Your progress report must be completed to the satisfaction of the Science Procurement Manager before progress claims will be processed for payment.

The following points concerning the attached example should be noted:

1) Reports actual progress to the end of August.

2) Actuals by month are recorded on the bottom line at the left of the date line and Estimate to Complete by month to the right of the date line.

3) MECHANICAL SUBSYSTEM Material Procurement started one month late, is projected to be completed on time, has cost $4M and the Estimate to Complete is $1M. Total subtask is expected to cost $5M.

4) MECHANICAL SUBSYSTEM Assembly is expected to start one month late and to be completed one month late. The expected late completions are to be highlighted using broken lines.

5) ELECTRICAL SUBSYSTEM Assembly started one month early and is expected to be completed one month early.

6) DISPLAY CONTROL SUBSYSTEM Procurement is 50% complete in terms of cost. The estimated completion date has slipped 2 months.

7) SYSTEM INTEGRATION AND SYSTEM TEST are both expected to start one month late reflecting the one month delay in MECHANICAL SUBSYSTEM Fabrication and Assembly.

8) As of the end of August, the total contract cost is expected to be $26M ($12.7M Actual plus $13.3M E.T.C.) or to equal the planned cost of $26M. The contract is expected to be completed one month later than planned.

FORMULE DE PROJET DE CONTRAT ET RAPPORT

Instructions aux entrepreneurs

Cette formule a un double but; elle sert premièrement à planifier et estimer le travail, et deuxièmement, à vérifier, tout au long de l'exécution du contrat, si les travaux se déroulent selon le plan.

PLAN PROPOSÉ

Les plans concernant les travaux et les coûts prévus doivent être établis sur la "Formule de projet de contrat et de rapport" DSS-MAS 9143-3 et doivent être présentés comme faisant partie de votre proposition. Le plan doit faire état de la façon dont vous prévoyez mettre le contrat à exécution en divisant le travail en tâches et en donnant, pour chaque tâche, une estimation du coût et un calendrier d'exécution. Ci-joint à la page I un exemple de formule remplie.

Utilisez des pages additionnelles si le nombre de tâches dépasse 15 ou si la durée du contrat est de plus de douze mois. Pour les gros contrats d'une valeur supérieure à $1M, divisez le travail à accomplir en tâches principales que vous subdiviserez par la suite en tâches secondaires. Pensez, par exemple, à un système divisé en sous-systèmes, qui, à leur tour, sont subdivisés en sous-tâches, comme des composants du sous-système.

Vous devrez réviser votre plan pour tenir compte des résultats des négociations; le plan révisé fera partie du contrat.

RAPPORT DE SITUATION

Lorsqu'un contrat est adjugé, il faut remplir un rapport de situation mensuel indiquant la date à laquelle chaque tâche a été entreprise, ainsi que la date prévue d'achèvement de chaque tâche, la somme dépensée tous les mois pour chaque tâche et le coût prévu d'achèvement par tâche et par mois et présenter ce rapport de la façon indiquée à la page II ci-jointe, à moins qu'il n'en soit indiqué autrement dans le contrat.

NOTA: Le numéro de dossier du contrat, le numéro de série et la durée actuelle en mois doivent être inscrits dans les cases correspondantes du premier rapport et des rapports subséquents. La fin de la période visée par le rapport doit être indiquée au moyen d'un trait vertical plein après le mois en question. Le rapport de situation doit être jugé satisfaisant par le directeur de l'approvisionnement scientifique avant que les demandes d'accompte ne soient traitées.

Soulignons les points suivants en ce qui concerne l'exemple annexé:

1) Les progrès, y compris ceux accomplis à la toute fin du mois d'août, figurent sur le rapport.

2) Les coûts réels, par mois, figurent en bas, à gauche du trait vertical plein indiquant la fin de la période visée par le rapport; le coût prévu pour l'exécution complète, en bas, à droite du trait vertical.

3) Ainsi, on voit que l'achat de matériel pour le sous-système mécanique a commencé un mois en retard, qu'on prévoit qu'il sera terminé à la date prévue. Cette tâche a coûté jusqu'ici $4M et on prévoit qu'elle coûtera un autre million d'ici à la fin des travaux. On prévoit donc qu'en tout, cette tâche aura coûté $5M.

4) L'assemblage du sous-système mécanique commencera probablement un mois en retard et se terminera aussi un mois en retard. Il faut mettre en relief les retards prévus au moyen de pointillés.

5) L'assemblage du sous-système électronique a débuté un mois en avance et devrait être terminé un mois en avance.

6) L'achat du sous-système de contrôle de l'affichage est exécuté à 50% en ce qui touche les coûts. La date prévue d'achèvement a toutefois été reportée de deux mois.

7) L'intégration et les vérifications du système devraient commencer deux mois en retard à cause du retard accusé au niveau de la fabrication et de l'assemblage du sous-système mécanique.

8) À la fin du mois d'août, on prévoit que le coût total du contrat sera de $26M ($12.7M déjà engagés et une dépense de $13.3M de prévue), c'est-à-dire qu'il atteindra le coût de $26M. La date d'achèvement a toutefois été reportée d'un mois.

Supply and Services Canada / Approvisionnements et Services Canada

DSS MAS 9143-3 (4/81)

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT

CONTRACTOR – ENTREPRENEUR

FILE NO. – N° DU DOSSIER	SERIAL NO. – N° DE SÉRIE

TASK DESCRIPTION DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COUT DE LA TÂCHE		
	1	2	3	4	5	6	7	8	9	10	11	12	PLANNED PRÉVU À L'ORIGINE	ACTUAL PRÉSENTEMENT	E.T.C. À VENIR
PLANNED COST BY MONTH COUT PRÉVU POUR CHAQUE MOIS													PLAN		
ACT. PRÉSENT. / E.T.C. BY MONTH PRÉVISION POUR CH. MOIS														ACTUAL COUTS RÉELS	E.T.C. À VENIR

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DDS MAS 9143-1 (4/81)

Page 1

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: GISMO DEVELOPMENT, ENGINEERING MODEL

CONTRACTOR – ENTREPRENEUR: ACME INDUSTRIES LTD.

FILE NO. – n° DU DOSSIER

SERIAL NO. – n° DE SÉRIE

TASK DESCRIPTION DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COÛT DE LA TÂCHE		
	1 MAY MAI	2 JUNE JUIN	3 JULY JUILLET	4 AUG. AOÛT	5 SEPT.	6 OCT.	7 NOV.	8 DEC. DÉC.	9 JAN. JANV.	10 FEB. FÉV.	11 MAR. MARS	12 APR. AVR.	PLANNED PRÉVU À L'ORIGINE	ACTUAL PRÉSENTEMENT	E.T.C. À VENIR
													ALL NUMBERS IN MILLIONS TOUS LES CHIFFRES REPRÉSENTENT DES MILLIONS		
MECHANICAL SUBSYSTEM SOUS-SYSTÈME MÉCANIQUE													6M		
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													3M		
FABRICATION													2M		
ASSEMBLY ASSEMBLAGE															
ELECTRICAL SUBSYSTEM SOUS-SYSTÈME ÉLECTRIQUE													2,5M		
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													2,5M		
FABRICATION													1M		
ASSEMBLY ASSEMBLAGE															
DISPLAY, CONTROL SUBSYSTEM SOUS-SYSTÈME DE CONTRÔLE DE L'AFFICHAGE													2M		
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													2M		
FABRICATION													1M		
ASSEMBLY ASSEMBLAGE													3M		
SYSTEM INTEGRATION INTÉGRATION DU SYSTÈME													2M		
SYSTEM TEST VÉRIFICATION DU SYSTÈME															
													PLAN 26M		
PLANNED COST BY MONTH COÛT PRÉVU POUR CHAQUE MOIS	1,5M	3,1M	3,6M	6,1M	5,1M	2,1M	1,6M	1M	1M	1M	1M			ACTUAL COSTS TO DATE	E.T.C. À VENIR
ACT. PRÉSENT. / E.T.C. BY MONTH PRÉVISIONS POUR CE MOIS															

Supply and Services Canada | Approvisionnements et Services Canada

DSS MAS 9143 2 (4/81)

CONTRACT PLAN AND REPORT FORM – FORMULE DE PROJET DE CONTRAT ET DE RAPPORT

CONTRACT TITLE – TITRE DU CONTRAT: GISMO DEVELOPMENT, ENGINEERING MODEL

CONTRACTOR – ENTREPRENEUR: ACME INDUSTRIES LTD.

FILE NO. – N° DU DOSSIER

SERIAL NO – N° DE SÉRIE

TASK DESCRIPTION / DESCRIPTION DE LA TÂCHE	TASK DURATION IN MONTHS – DURÉE DE LA TÂCHE EN MOIS												TASK COST – COÛT DE LA TÂCHE		
	1 MAY MAI	2 JUNE JUIN	3 JULY JUILLET	4 AUG. AOÛT	5 SEPT. SEPT.	6 OCT. OCT.	7 NOV. NOV.	8 DEC. DÉC.	9 JAN. JANV.	10 FEB. FÉV.	11 MAR. MARS	12 APR. AVRIL	PLANNED PRÉVU À L'ORIGINE	ACTUAL PRÉSENTEMENT	E.T.C. À VENIR
													ALL NUMBERS IN MILLIONS TOUS LES CHIFFRES REPRÉSENTENT DES MILLIONS		
MECHANICAL SUBSYSTEM SOUS-SYSTÈME MÉCANIQUE															
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													6M	4M	1M
FABRICATION													3M	1.2M	1.8M
ASSEMBLY ASSEMBLAGE													2M	–	2M
ELECTRICAL SUBSYSTEM SOUS-SYSTÈME ÉLECTRIQUE															
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													2.5M	2.5M	–
FABRICATION													2.5M	2.5M	–
ASSEMBLY ASSEMBLAGE													1M	.5M	.5M
DISPLAY, CONTROL SUBSYSTEM SOUS-SYSTÈME DE CONTRÔLE DE L'AFFICHE															
MATERIAL PROCUREMENT ACHAT DE MATÉRIEL													2M	1M	1M
FABRICATION													2M	1M	1M
ASSEMBLY ASSEMBLAGE													1M	–	1M
SYSTEM INTEGRATION INTÉGRATION DU SYSTÈME													3M	–	3M
SYSTEM TEST VÉRIFICATION DU SYSTÈME													2M	–	2M
PLANNED COST BY MONTH COÛT PRÉVU POUR CHAQUE MOIS	1.5M	3.1M	3.6M	5.1M	6.1M	2.1M	1.6M	1M	1M	1M	1M		PLAN 26M		
ACT. PRÉSENT. / E.T.C. BY MONTH PRÉVISION POUR LE MOIS	5M	3M	4.1M	5.1M	4.6M	2.1M	1.1M	1.6M	1M	1M	1M	1M		ACTUAL COÛTS RÉELS 12.7M	E.T.C. À VENIR 13.3M

APPENDIX "D"

PROGRESS PAYMENT ROUTING

FROM: D. COMRIE CONSULTING LTD.

TO: DIANE LAMOUREUX

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

CLAIM NO.:

DSS FILE NO.: 39SQ.23440-8-9171

SERIAL NO.: 23440-8-9171/01-SQ

FINANCIAL CODE: 234-131-000000-303701-0433

The original, four (4) copies of the progress claim DSS 1111 and two (2) copies of supporting documentation are to be forwarded for certification as follows:

ADDRESSEE	INITIALS	DATE SENT TO NEXT ADDRESSEE

(1) Senior Purchasing Assistant

Mrs. Diane Lamoureux
DSS/Science Branch
Place du Portage, Phase III, 11C1
11 Laurier Street
Hull, Quebec K1A 0S5

(2) Scientific Authority

Mr. V.M. Malhotra
Energy, Mines and Resources
CANMET, MSL Division
555 Booth Street
Ottawa, Ontario
K1A 0G1

(3) Accounts Office

Mrs. Shirley Ristow
Energy, Mines and Resources
CANMET, Contracts Office
Rm 167A, 555 Booth Street
Ottawa, Ontario
K1A 0G1

NOTE: SEE "DELIVERABLES" CLAUSE FOR ROUTING OF OTHER DELIVERABLES

APPENDIX "G"

SAMPLE TITLE PAGE

TITLE: TO DEVELOP GEOPOLYMER FORMULATIONS AND TO DETERMINE THEIR MECHANICAL AND DURABILITY PROPERTIES FOR CAPPING OF PYRITIC SLATE OUTCROPS AT HALIFAX AIRPORT

FINAL REPORT

BY:

Work on the project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources Canada.

DSS FILE NO.: 14SQ.23440-8-9171

DSS CONTRACT SERIAL NO.: 23440-8-9171/01-SQ

CANMET PROJECT NO.:

CANMET SCIENTIFIC AUTHORITY:

DATE:

APPENDIX 2. PHASE 1 MIX FORMULATIONS & PHYSICAL TESTING DATA

TABLE 1(a): EFFECT OF DIFFERENT BINDER FORMULATIONS ON PRODUCT CHARACTERISTICS

	SAMPLE NUMBER								
	10-25-1	10-25-2	10-25-3	10-25-4	10-25-5	10-25-6	10-25-7	10-25-8	10-25-9
INORBOND									
TYPE A	32.9%		13.8%	15.1%		26.8%	13.2%	13.5%	34.6%
TYPE B									
TYPE C									
TYPE D									
TYPE E									
Slag									
Silica Fume						11.6%	5.7%	5.8%	
Ca(OH)2	11.6%		4.8%	5.3%		6.0%	2.9%	3.0%	5.5%
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	38.9%	14.5%	16.3%			38.9%		19.5%	18.5%
Caustic 1	16.7%	6.2%	7.0%			16.7%		8.4%	7.9%
Caustic 2									
GP52A				25.6%	21.1%		27.2%		
GP52B		16.6%			16.9%				
Sand		62.6%	58.2%	54.0%	61.9%		51.0%	49.8%	28.5%
Water									5.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

NOTES:
1. Compositions refer to weight percentages
2. Inorbond, IB and GP52 components represent different varieties of geopolymeric binder

	10-25-10	10-28-1	10-28-2	10-28-3	10-28-4	10-28-5	10-28-6	10-28-7	10-28-8
INORBOND									
TYPE A	38.9%	28.9%		22.8%	17.7%	22.2%	17.0%		17.0%
TYPE B								12.9%	
TYPE C									
TYPE D									
TYPE E									
Slag									
Silica Fume									
Ca(OH)2	10.5%				5.0%		4.8%	3.6%	4.8%
CaF2					6.3%			4.5%	
CaO		10.1%		8.0%					
CaSO4							10.2%		
IB DRY ACTIVATOR									
Gypsum									10.2%
IB LIQ. ACTIVATOR	35.4%	42.7%	25.2%	26.9%	25.3%	77.8%	24.3%	18.4%	24.3%
Caustic 1	15.2%	18.2%		11.5%	10.8%		10.4%	7.9%	10.4%
Caustic 2									
GP52A									
GP52B									
Sand			74.8%	30.8%	34.9%		33.4%	52.7%	33.4%
Water									
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	10-28-9	11-3-1	11-4-1	11-4-2	11-7-1	11-7-2	11-7-3	11-7-4	11-7-5
INORBOND									
TYPE A	8.9%	9.3%							
TYPE B									
TYPE C									
TYPE D			24.3%	13.2%	25.0%	23.8%	22.5%	21.3%	20.0%
TYPE E									
Slag		12.5%		13.2%					
Silica Fume									
Ca(OH)2		3.3%				1.3%	2.5%	3.8%	5.0%
CaF2	5.7%		6.7%						
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	12.8%	21.9%	22.5%	17.6%	17.5%	17.5%	17.5%	17.5%	17.5%
Caustic 1	5.5%	9.4%	9.6%	7.6%	7.5%	7.5%	7.5%	7.5%	7.5%
Caustic 2									
GP52A									
GP52B									
Sand	67.2%	43.8%	37.0%	48.5%	50.0%	50.0%	50.0%	50.0%	50.0%
Water									
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-7-6	11-8-1	11-8-2	11-8-3	11-8-4	11-8-5	11-9-1	11-9-2	11-9-3
INORBOND									
TYPE A									
TYPE B									
TYPE C									
TYPE D	33.2%	20.0%	14.5%	11.4%	18.0%	20.0%	13.8%	12.5%	14.7%
TYPE E									
							1.4%	3.1%	5.9%
Slag							3.5%	5.0%	1.5%
Silica Fume									
Ca(OH)2		5.0%	3.6%	2.9%	4.5%	5.0%			
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
							14.5%	13.2%	15.4%
IB LIQ. ACTIVATOR	16.9%	17.5%	12.7%	10.0%	11.2%		6.2%	5.6%	6.6%
Caustic 1	7.3%	7.5%	5.4%	4.3%	11.2%				
Caustic 2									
						25.0%			
GP52A									
GP52B									
Sand	42.5%	50.0%	54.3%	57.1%	55.0%	50.0%	60.6%	60.5%	56.0%
Water			9.5%	14.3%					
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

INORBOND	11-9-4	11-9-5	11-9-6	11-9-7	11-9-8	11-10-1	11-10-2	11-10-3	11-10-4
TYPE A									
TYPE B									
TYPE C									
TYPE D	6.4%	6.3%	6.3%	4.9%	6.3%	9.1%	6.1%	7.6%	4.3%
TYPE E									
Slag	6.4%	6.3%	6.3%	4.9%	6.3%	9.1%	13.0%	9.1%	9.3%
Silica Fume	6.4%	6.3%	6.3%	4.9%	6.3%	1.5%	0.6%	3.0%	0.4%
Ca(OH)2									
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR									
Gypsum									
IB LIQ. ACTIVATOR	13.4%	1.9%		13.7%	9.4%	13.8%	13.8%	13.8%	9.9%
Caustic 1	5.8%	16.9%		5.9%	9.4%	5.9%	5.9%	5.9%	4.3%
Caustic 2									
GP52A			18.8%						
GP52B									
Sand	61.7%	62.5%	62.5%	65.8%	62.5%	60.6%	60.6%	60.6%	67.7%
Water									4.1%
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-10-5	11-10-6	11-11-1	11-11-2	11-15-1	11-15-2	11-15-3	11-25-1	11-25-2
INORBOND									
TYPE A									
TYPE B									
TYPE C									
TYPE D	8.9%	8.3%						5.0%	5.0%
TYPE E			6.0%	6.0%	18.9%	9.0%			
Slag	8.9%	3.3%	13.0%	13.0%				10.8%	10.8%
Silica Fume	0.9%		1.0%	1.0%	1.1%	0.6%		0.8%	0.8%
Ca(OH)2	1.3%	3.3%							
CaF2									
CaO									
CaSO4									
IB DRY ACTIVATOR					2.2%	1.3%	33.3%		
Gypsum									
IB LIQ. ACTIVATOR	14.0%	10.5%	14.0%	2.0%	15.6%	9.0%		14.5%	14.5%
Caustic 1	6.0%	4.5%		18.0%		3.8%			6.2%
Caustic 2			6.0%		6.7%			6.2%	
GP52A									
GP52B									
Sand	60.0%	60.0%	60.0%	60.0%	55.6%	69.9%	50.0%	62.6%	62.6%
Water		10.0%				6.4%	16.7%		
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

	11-25-3	11-25-4
INORBOND		
TYPE A		
TYPE B		
TYPE C		
TYPE D		5.0%
TYPE E		
Slag		10.8%
Silica Fume		0.8%
Ca(OH)2		
CaF2		
CaO		
CaSO4		
IB DRY ACTIVATOR		
Gypsum		
IB LIQ. ACTIVATOR	14.5%	
Caustic 1	6.2%	
Caustic 2		
GP52A		20.8%
GP52B	16.6%	
Sand	62.6%	62.6%
Water		
TOTAL	100.0%	100.0%

TABLE 1(b): EFFECT OF DIFFERENT BINDER FORMULATIONS ON PRODUCT CHARACTERISTICS

	SAMPLE NUMBER								
	10-25-1	10-25-2	10-25-3	10-25-4	10-25-5	10-25-6	10-25-7	10-25-8	10-25-9
REACTION TIME(min)	15	40	5	5	30	10	23	5	0
SETTING TIME(min)	0	0	15	0	0	0		10	0
COMMENTS:	MIXTURE SET BEFORE SAND ADDED.	SET NEXT DAY. NO CRACKS.	CRACKED WHEN DEMOLDE WILL NOT DISSOLVE IN H2O.	SET NEXT DAY. NO CRACKS. SOFT. HARD NEXT WEEK.	SET NEXT DAY. NO CRACKS.	MIXTURE SET BEFORE SAND ADDED.	SET SLOWLY. CRACKED BADLY.	BADLY CRACKED.	FLASH SET.
EVALUATION									
VISCOSITY-	0	5	1	1	5	0	1	2	0
SET TIME-	0	5	2	2	5	0	1	2	0
CRACKING-	0	5	1	5	5	0	1	0	0
1 DAY HARDNESS-	0	5	2	1	5	0	1	1	0
7 DAY HARDNESS-	0	5	2	5	5	0	0	3	0
SCORE	0	25	8	14	25	0	4	8	0

NOTES:

1. Reaction time: Delay time before adding aggregate
2. Set time: Time to hardening and zero slump.
3. Viscosity: Thickness of mix (qualitative); 5= maximum viscosity
4. Cracking: Qualitative evaluation of surface cracking (severity and frequency)
5. Hardness: Qualitative evaluation of surface hardness (5=maximum)
6. Score: Sum of qualitative evaluations.

	10-25-10	10-28-1	10-28-2	10-28-3	10-28-4	10-28-5	10-28-6	10-28-7	10-28-8
REACTION TIME(min)	5	0	N/A	0	9	0	0	5	0
SETTING TIME(min)	0	0	1 DAY	30	30	3 DAYS	0	1 DAY	0
COMMENTS:	SET CRACKED.	FLASH SET. HOT.	SET SLOWLY. NO CRACKS. DISSOLV IN WATER.	SAND MIXED WITH POWDER. LIQUID ADDED LATER.	CRACKED BADLY.	DISSOLV IN WATER.	FLASH SET.	SOME CRACKS.	FLASH SET.
EVALUATION									
VISCOSITY-	1	0	3	3	2	2	0	3	0
SET TIME-	2	0	0	3	3	3	0	4	0
CRACKING-	0	0	5	2	0	5	0	1	0
1 DAY HARDNESS-	2	0	0	2	1	0	0	1	0
7 DAY HARDNESS-	4	0	5	4	5	0	0	5	0
SCORE	9	0	13	14	11	10	0	14	0

	10-28-9	11-3-1	11-4-1	11-4-2	11-7-1	11-7-2	11-7-3	11-7-4	11-7-5
REACTION TIME(min)	20	5	5	5	5	15	5	5	5
SETTING TIME(min)	N/A	10	N/A	1 DAY	N/A	3 DAYS	1 DAY	1 DAY	20
COMMENTS:	WOULD NOT SET.	VERY MINOR CRACKING HARD.	WOULD NOT SET. CaF2 FINE.	ALMOST NO CRACKS.	DID NOT SET.	SOME SMALL CRACKS.	SOME SMALL CRACKS.	NO CRACKS.	NO CRACKS.
EVALUATION									
VISCOSITY-	5	3	3	4	2	2	2	2	2
SET TIME-	0	4	0	4	0	1	2	3	4
CRACKING-	0	4	0	4	0	4	4	5	5
1 DAY HARDNESS-	0	4	0	3	0	2	3	3	4
7 DAY HARDNESS-	0	5	0	5	0	5	5	5	5
SCORE	5	20	3	20	2	14	16	18	20

	11-7-6	11-8-1	11-8-2	11-8-3	11-8-4	11-8-5	11-9-1	11-9-2	11-9-3
REACTION TIME(min)	5	5	5	5	5	5	5	5	5
SETTING TIME(min)	N/A	20	0	1	1 DAY	1 DAY	2 DAYS	2 DAYS	1 DAY
COMMENTS:	DID NOT SET.	SOME SMALL CRACKS. INITIALLY SOFT.	FLASH SET.	INITIAL LOW VISCOS. FLASH SET. CRACKED.	BROKE ON REMOVAL FROM MOLD.	CRACKED SLIGHTLY.	CRACKED BADLY.	CRACKED SLIGHTLY.	SLIGHT CRACKS.
EVALUATION									
VISCOSITY-	2	3	0	4	2	3	3	4	5
SET TIME-	0	4	0	0	4	4	2	2	5
CRACKING-	0	4	0	1	3	3	3	4	4
1 DAY HARDNESS-	0	2	0	1	2	3	0	0	4
7 DAY HARDNESS-	0	5	0	3	3	4	5	5	5
SCORE	2	18	0	9	14	17	13	15	23

	11-9-4	11-9-5	11-9-6	11-9-7	11-9-8	11-10-1	11-10-2	11-10-3	11-10-4
REACTION TIME(min)	5	10	12	12	17	30	30	30	30
SETTING TIME(min)	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY	1 DAY
COMMENTS:	MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	SOFT @ FIRST. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH SAND. MINOR CRACKS.
EVALUATION									
VISCOSITY-	3	4	4	4	4	4	5	5	4
SET TIME-	5	4	5	5	5	5	5	5	5
CRACKING-	4	5	5	5	5	4	4	4	4
1 DAY HARDNESS-	4	2	3	4	4	4	4	4	4
7 DAY HARDNESS-	5	3	5	5	5	5	5	5	5
SCORE	21	18	22	23	23	22	23	23	22

	11-10-5	11-10-6	11-11-1	11-11-2	11-15-1	11-15-2	11-15-3	11-25-1	11-25-2
REACTION TIME(min)	30	5	30	30	30	30	N/A	30	30
SETTING TIME(min)	1 DAY	0	4 HRS	2 DAYS	0	0	1 DAY	1 DAY	1 DAY
COMMENTS:	FUME ADDED WITH SAND. NO VISIBLE CRACKS.	FLASH SET. HARD ON BOTTOM.	FUME ADDED WITH SAND. MINOR CRACKS.	FUME ADDED WITH SAND. NO VISIBLE CRACKS.	NOT SET NEXT DAY.	NOT SET NEXT DAY.	A BIT CRUMBLY NEXT DAY.	GOOD SURFACE, HARD, SMOOTH	GOOD SURFACE, HARD, SMOOTH
EVALUATION									
VISCOSITY-	5	5	5	5	2	2	5	5	5
SET TIME-	5	0	5	4	0	0	5	5	5
CRACKING-	5	0	4	5	0	0	5	5	5
1 DAY HARDNESS-	4	0	4	4	0	0	3	4	4
7 DAY HARDNESS-	5	0	5	5	0	0	4	4	4
SCORE	24	5	23	23	2	2	22	23	23

	11-25-3	11-25-4
REACTION TIME(min)	30	30
SETTING TIME(min)	1 DAY	1 DAY
COMMENTS:	PERFECT SURFACE, V.HARD, SMOOTH	GOOD SURFACE, HARD, SMOOTH
EVALUATION		
VISCOSITY-	5	5
SET TIME-	5	5
CRACKING-	5	5
1 DAY HARDNESS-	5	4
7 DAY HARDNESS-	5	4
SCORE	25	23

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-1	gram	40.0	60.0				13.7	113.7	100	1.5	1.5
	% wet	35.2	52.8				12.0				
	% dry	40.0	60.0								
H-2	gram	20.0	80.0				47.4	147.4	100	4.0	4
	% wet	13.6	54.3				32.2				
	% dry	20.0	80.0								
H-3	gram	20.0	40.0	40.0			20.6	120.6	100	2.0	4
	% wet	16.6	33.2	33.2			17.1	100.0			
	% dry	20.0	40.0	40.0							
H-4	gram	20.0	40.0	20.0	20.0		33.5	133.5	100	2.0	4
	% wet	15.0	30.0	15.0	15.0		25.1	100.0			
	% dry	20.0	40.0	20.0	20.0						
H-5	gram	20.0	40.0	20.0	20.0		10.6	110.6	100	2.0	4
	% wet	18.1	36.2	18.1	18.1		9.6	100.0			
	% dry	20.0	40.0	20.0	20.0						
H-6	gram	20.0	30.0	40.0	10.0		3.2	103.2	100	1.5	4
	% wet	19.4	29.1	38.8	9.7		3.1	100.0			
	% dry	20.0	30.0	40.0	10.0						
H-7	gram	20.0	20.0	20.0	20.0	20.0	12.2	112.2	100	1.0	4
	% wet	17.8	17.8	17.8	17.8	17.8	10.9	100.0			
	% dry	20.0	20.0	20.0	20.0	20.0					

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-8	gram	20.0	20.0	20.0	20.0	20.0	17.7	117.7	100	1.0	4
	% wet	17.0	17.0	17.0	17.0	17.0	15.0	100.0			
	% dry	20.0	20.0	20.0	20.0	20.0					
H-9	gram	20.0	30.0		10.0	40.0	15.2	115.2	100	1.5	4
	% wet	17.4	26.0		8.7	34.7	13.2	100.0			
	% dry	20.0	30.0		10.0	40.0					
H-10	gram	20.0	20.0	60.0			2.9	102.9	100	1.0	4
	% wet	19.4	19.4	58.3			2.8	100.0			
	% dry	20.0	20.0	60.0							
H-11	gram	20.0	20.0	30.0		30.0	15.7	115.7	100	1.0	4
	% wet	17.3	17.3	25.9		25.9	13.6	100.0			
	% dry	20.0	20.0	30.0		30.0					
H-12	gram	50.0	65.0	50.0			11.0	176.0	165	1.3	2.3
	% wet	28.4	36.9	28.4			6.3	100.0			
	% dry	30.3	39.4	30.3							
H-13	gram	50.0	100.0	50.0			33.5	233.5	200	2.0	3
	% wet	21.4	42.8	21.4			14.3	100.0			
	% dry	25.0	50.0	25.0							
H-14	gram	20	65	15			22.9	122.9	100	3.3	4
	% wet	16.3	52.9	12.2			18.6	100.0			
	% dry	20.0	65.0	15.0							

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-15	gram	20	70	10			29.2	129.2	100	3.5	4
	% wet	15.5	54.2	7.7			22.6	100.0			
	% dry	20.0	70.0	10.0							
H-16	gram	20	60	20			27.1	127.1	100	3.0	4
	% wet	15.7	47.2	15.7			21.3	100.0			
	% dry	20.0	60.0	20.0							
H-17	gram	20	75				32.3	127.3	95	3.8	3.75
	% wet	15.7	58.9				25.4	100.0			
	% dry	21.1	78.9								
H-18	gram	14	76	20			30.3	140.3	110	5.4	6.9
	% wet	10.0	54.2	14.3			21.6	100.0			
	% dry	12.7	69.1	18.2							
H-19	gram	14	71	15			27.5	127.5	100	5.1	6.1
	% wet	11.0	55.7	11.8			21.6	100.0			
	% dry	14.0	71.0	15.0							
H-20	gram	19.95	65.05	15			20.1	120.1	100	3.3	4.0
	% wet	16.6	54.2	12.5			16.7	100.0			
	% dry	20.0	65.1	15.0							
H-21	gram	30.1	60.9	30			7.9	128.9	121	2.0	3.0
	% wet	23.4	47.2	23.3			6.1	100.0			
	% dry	24.9	50.3	24.8							

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-22	gram	30.1	69.9	20			9.2	129.2	120	2.3	3.0
	% wet	23.3	54.1	15.5			7.1	100.0			
	% dry	25.1	58.3	16.7							
H-23	gram	17.5	67.5	15			18.3	118.3	100	3.9	4.7
	% wet	14.8	57.1	12.7			15.5	100.0			
	% dry	17.5	67.5	15.0							
H-24	gram	301	699	200			127.3	1327.3	1200	2.3	3.0
	% wet	22.7	52.7	15.1			9.6	100.0			
	% dry	25.1	58.3	16.7							
H-25	gram	250.81	582.49	166.7			211.9	1211.9	1000	2.3	3.0
	% wet	20.7	48.1	13.8			17.5	100.0			
	% dry	25.1	58.2	16.7							
H-26	gram	199.5	650.5	150			333.1	1333.1	1000	3.3	4.0
	% wet	15.0	48.8	11.3			25.0	100.0			
	% dry	20.0	65.1	15.0							
H-27	gram	20	40	40			22.3	122.3	100	2.0	4.0
	% wet	16.4	32.7	32.7			18.2	100.0			
	% dry	20.0	40.0	40.0							
H-28	gram	19.95	65.05	15			27.5	127.5	100	3.3	4.0
	% wet	15.6	51.0	11.8			21.6	100.0			
	% dry	20.0	65.1	15.0							

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 2: FLY ASH BASED MIX DESIGNS

		GP	ASH	SAND	FUME	CLAY	WATER	Wet Sum	Dry Sum	ASH/GP	DRY/GP
H-29	gram	30.1	69.9	20			20	140.0	120	2.3	3.0
	% wet	21.5	49.9	14.3			14.3	100.0			
	% dry	25.1	58.3	16.7							
H-30	gram	50		40	10		2.1	102.1	100	0.2	1.0
	% wet	49.0		39.2	9.8		2.1	100.0			
	% dry	50.0		40.0	10.0						
H-31	gram	40		50	10		4.1	104.1	100	0.25	1.5
	% wet	38.4		48.0	9.6		3.9	100.0			
	% dry	40.0		50.0	10.0						
H-32	gram	50		30	20		6.3	106.3	100	0.4	1.0
	% wet	47.0		28.2	18.8		5.9	100.0			
	% dry	50.0		30.0	20.0						

NOTES:

1. Gepolymer used consists of equal parts GP52A (liquid) and GP52B (powder)
2. "% dry" refers to weight percentages of constituents without water

TABLE 3(a): FLY ASH BASED GEOPOLYMER CEMENT MIX DESIGNS
(gram amounts)

	GP52	ASH	SAND	WATER	Total (wet)	Total(dry)
12-29-1	50	50		18.6	118.6	100
12-29-2	50	50		10	110	100
12-29-3	50	50	25	29.2	154.2	125
12-29-4	50	50	25	15	140	125
12-29-5	50	50	50	20	170	150
12-29-6	50	75		19.5	144.5	125
12-29-7	50	75		21	146	125
12-29-8	50	75		26	151	125
12-29-9	25	37.5	12.5	15	90	75
12-29-10	25	37.5	25	20	107.5	87.5
12-29-11	25	37.5	37.5	23	123	100
12-29-12	25	37.5	37.5	20	120	100
12-29-13	25	50		27	102	75
12-29-14	25	50		16	91	75
12-29-15	25	50	12.5	19	106.5	87.5
12-29-16	25	50	25	22	122	100

TABLE 3(b): FLY ASH BASED GEOPOLYMER CEMENT MIX DESIGNS
(weight percentage basis, excluding water)

	GP52	ASH	SAND	ASH:GP	AGGREGATE:GP
12-29-1	50	50	0	1	1
12-29-2	50	50	0	1	1
12-29-3	40	40	20	1	1.5
12-29-4	40	40	20	1	1.5
12-29-5	33	33	33	1	2
12-29-6	40	60	0	2	1.5
12-29-7	40	60	0	2	1.5
12-29-8	40	60	0	2	1.5
12-29-9	33	50	17	2	2
12-29-10	29	43	29	2	2.5
12-29-11	25	38	38	2	3
12-29-12	25	38	38	2	3
12-29-13	33	67	0	2	2
12-29-14	33	67	0	2	2
12-29-15	29	57	14	2	2.5
12-29-16	25	50	25	2	3

TABLE 4(a): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(gram amounts)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SLAG	FLY ASH	Gram Total	SET TIME (min)
20-6-1	18.0	27.0	55.0	70.0				170.0	3
20-6-2	22.5	22.5	55.0	70.0				170.0	4
20-6-3	27.0	18.0	55.0	70.0				170.0	5.25
20-6-4	31.5	13.5	55.0	70.0				170.0	9
20-6-5	36.0	9.0	55.0	70.0				170.0	0.5
20-6-6	22.5	22.5	55.0	70.0				170.0	4
20-6-7	22.5	22.5	55.0	70.0				170.0	4
20-6-8		18.0	55.0	93.1				193.1	-
20-6-9	20.0	20.0	60.0	70.0				170.0	6
20-6-10	25.0	25.0	50.0	70.0				170.0	2
20-6-11	9.6	9.6	45.0	100.1				164.3	13
6-21-1	22.5	22.5	55.0		90.0			190.0	
6-21-2	13.5	13.5	33.0	30.0	50.0			140.0	1-2
6-21-2(A)	13.5	13.5	33.0	30.0	50.0			140.0	5
6-21-3	5.1	5.1	12.4	5.0	22.5			50.0	1-2
6-22-1	4.5	4.5	13.5	5.0	22.5			50.0	1-2
6-22-2	5.1	5.1	12.4	10.0	15.0			47.5	
6-26-1	7.9	7.9	19.3	13.2	15.0			63.2	
6-26-2	7.9	7.9	19.3	11.9	15.0			61.9	
6-26-3	3.8	3.8	9.4	10.0	30.0			57.1	
6-26-4	2.0	2.0	6.0	10.0	30.0			50.0	
6-26-5	3.5	3.5	13.1	20.7	61.4			102.3	
6-28-1	11.2	11.2	27.5		50.0			99.9	7.5

TABLE 4(a): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(gram amounts)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SLAG	FLY ASH	Gram Total	SET TIME (min)
6-28-2	11.2	11.2	27.5		50.0			99.9	6
6-28-3	11.2	11.2	27.5		41.0			90.9	5
6-28-4	11.2	11.2	27.5		50.0			99.9	5
7-7-1	13.2	13.2	32.4	41.2				100.0	4
7-7-2	13.2	13.2	32.4	41.2				100.0	4
7-7-3	13.2	13.2	32.4	41.2				100.0	4
7-7-4	13.2	9.9	32.4	41.2		3.3		100.0	5
7-7-5	13.2	6.6	32.4	41.2		6.6		100.0	12
7-7-6	13.2	3.3	32.4	41.2		9.9		100.0	
7-22-2	10.0	10.0	20.0		20.0	20.0		80.0	
7-22-3	10.0	10.0	20.0		40.0			80.0	
7-22-4	12.5	12.5	25.0	20.0	30.0			100.0	
7-22-5	8.8	8.8	17.5	15.0	35.0	15.0		100.0	
7-22-6	8.8	8.8	17.5		65.0			100.0	
7-22-7	7.5	7.5	15.0	90.0	30.0			150.0	

TABLE 4(b): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(weight percentages)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SAND	FLY ASH	SET TIME (min)
20-6-1	10.6%	15.9%	32.4%	41.2%				3
20-6-2	13.2%	13.2%	32.4%	41.2%				4
20-6-3	15.9%	10.6%	32.4%	41.2%				5.25
20-6-4	18.5%	7.9%	32.4%	41.2%				9
20-6-5	21.2%	5.3%	32.4%	41.2%				0.5
20-6-6	13.2%	13.2%	32.4%	41.2%				4
20-6-7	13.2%	13.2%	32.4%	41.2%				4
20-6-8	14.0%	9.3%	28.5%	48.2%				-
20-6-9	11.8%	11.8%	35.3%	41.2%				6
20-6-10	14.7%	14.7%	29.4%	41.2%				2
20-6-11	5.8%	5.8%	27.4%	60.9%				13
6-21-1	11.8%	11.8%	28.9%		47.4%			
6-21-2	9.6%	9.6%	23.6%	21.4%	35.7%			
6-21-2(A)	9.6%	9.6%	23.6%	21.4%	35.7%			5
6-21-3	10.1%	10.1%	24.8%	10.0%	45.0%			
6-22-1	9.0%	9.0%	27.0%	10.0%	45.0%			
6-22-2	10.7%	10.7%	26.1%	21.1%	31.6%			
6-26-1	12.5%	12.5%	30.5%	20.9%	23.7%			
6-26-2	12.7%	12.7%	31.1%	19.2%	24.2%			
6-26-3	6.7%	6.7%	16.5%	17.5%	52.5%			
6-26-4	4.0%	4.0%	12.0%	20.0%	60.0%			
6-26-5	3.5%	3.5%	12.8%	20.2%	60.0%			
6-28-1	11.2%	11.2%	27.5%		50.1%			7.5
6-28-2	11.2%	11.2%	27.5%		50.1%			6

TABLE 4(b): EFFECT OF CEMENT, SAND, FLY ASH AND FIBRE ON SET TIMES IN MORTAR MIXES
(weight percentages)

ID #	INORBOND F	CEMENT	GP(A)	SAND	FIBRE	SAND	FLY ASH	SET TIME (min)
6-28-3	12.3%	12.3%	30.3%		45.1%			5
6-28-4	11.2%	11.2%	27.5%		50.1%			5
7-7-1	13.2%	13.2%	32.4%	41.2%				4
7-7-2	13.2%	13.2%	32.4%	41.2%				4
7-7-3	13.2%	13.2%	32.4%	41.2%				4
7-7-4	13.2%	9.9%	32.4%	41.2%	3.3%	3.3%		5
7-7-5	13.2%	6.6%	32.4%	41.2%	6.6%	6.6%		12
7-7-6	13.2%	3.3%	32.4%	41.2%	9.9%	9.9%		
7-22-2	12.5%	12.5%	25.0%		25.0%	25.0%		
7-22-3	12.5%	12.5%	25.0%		50.0%			
7-22-4	12.5%	12.5%	25.0%	20.0%	30.0%			
7-22-5	8.8%	8.8%	17.5%	15.0%	35.0%	15.0%		
7-22-6	8.8%	8.8%	17.5%		65.0%			
7-22-7	5.0%	5.0%	10.0%	60.0%	20.0%			

TABLE 4(c): EFFECT OF COMPONENT RATIOS ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-1	1.5	1.2	0.7	3
20-6-2	1.0	1.2	0.7	4
20-6-3	0.7	1.2	0.7	5.25
20-6-4	0.4	1.2	0.7	9
20-6-5	0.3	1.2	0.7	0.5
20-6-6	1.0	1.2	0.7	4
20-6-7	1.0	1.2	0.7	4
20-6-8	0.7	1.2	0.9	-
20-6-9	1.0	1.5	0.7	6
20-6-10	1.0	1.0	0.7	2
20-6-11	1.0	2.3	1.6	13

TABLE 4(d): EFFECT OF CEMENT CONTENT ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-1	1.5	1.2	0.7	3
20-6-2	1.0	1.2	0.7	4
20-6-3	0.7	1.2	0.7	5.25
20-6-4	0.4	1.2	0.7	9

TABLE 4(e): EFFECT OF LIQUID:POWDER RATIO ON SETTING TIMES

	CEMENT:IB-F	LIQUID:POWDER	AND:IB(A)	SET TIME
20-6-10	1.0	1.0	0.7	2
20-6-6	1.0	1.2	0.7	4
20-6-9	1.0	1.5	0.7	6
20-6-11	1.0	2.3	1.6	13

TABLE 5(a): MIX DESIGNS USED FOR STRENGTH TESTING
(gram amounts)

			AGGREGATE		
	GP(A)	GP(B)	Coarse	Fine	Fly Ash
2-7-1	11	9	45	135	
2-7-2	22	18	40	120	
2-7-3	33	27	35	105	
2-7-4	22	18	40	120	
2-7-5	20	20	60	100	
2-7-6	20	20	80	80	
2-7-7	20	20	100	60	
2-7-8	20	20	120	40	
2-7-33	17	13	42	128	
2-7-34	28	22	38	112	
2-8-9	22	14	40	120	4
2-8-10	22	10	40	120	8
2-8-11	22	6	40	120	12
2-8-12	22		40	120	18
2-8-13	18	18	40	124	
2-8-14	14	18	42	126	
2-8-15	10	18	42	130	
2-8-16	6	18	44	132	
2-8-17	18	18	40	120	4
2-8-18	14	18	40	120	8
2-8-19	10	18	40	120	12
2-8-20	6	18	40	120	16
2-7-2(a)	400	400	800	2400	

TABLE 5(b): MIX DESIGNS USED FOR STRENGTH TESTING

(weight percentages)

			AGGREGATE			Testing	L/D	Density	Strength
	GP(A)	GP(B)	Coarse	Fine	Fly Ash	Age	Ratio	(kg/cu. m)	(MPa)
2-7-1	5.5%	4.5%	22.5%	67.5%		n/a	n/a	n/a	n/a
2-7-2	11.0%	9.0%	20.0%	60.0%		2	0.883	2211	2.8
2-7-3	16.5%	13.5%	17.5%	52.5%		2	0.946	2303	9.4
2-7-4	11.0%	9.0%	20.0%	60.0%		2	0.882	2142	6.3
2-7-5	10.0%	10.0%	30.0%	50.0%		2	0.883	2295	5.7
2-7-6	10.0%	10.0%	40.0%	40.0%		2	0.875	2331	3.9
2-7-7	10.0%	10.0%	50.0%	30.0%		2	0.916	2354	16.2
2-7-8	10.0%	10.0%	60.0%	20.0%		2	0.883	2408	13.9
2-7-33	8.5%	6.5%	21.0%	64.0%		2	0.884	2243	1.9
2-7-34	14.0%	11.0%	19.0%	56.0%		2	0.896	2214	4.6
2-8-9	11.0%	7.0%	20.0%	60.0%	2.0%	2	0.894	2174	2.6
2-8-10	11.0%	5.0%	20.0%	60.0%	4.0%	2	0.875	2219	0.9
2-8-11	11.0%	3.0%	20.0%	60.0%	6.0%	2	0.879	2178	0.9
2-8-12	11.0%		20.0%	60.0%	9.0%	n/a	n/a	n/a	n/a
2-8-13	9.0%	9.0%	20.0%	62.0%		2	0.852	2216	1.8
2-8-14	7.0%	9.0%	21.0%	63.0%		2	0.885	2225	1.3
2-8-15	5.0%	9.0%	21.0%	65.0%		2	0.842	2224	0.9
2-8-16	3.0%	9.0%	22.0%	66.0%		n/a	n/a	n/a	n/a
2-8-17	9.0%	9.0%	20.0%	60.0%	2.0%	2	0.884	2243	3.2
2-8-18	7.0%	9.0%	20.0%	60.0%	4.0%	2	0.88	2265	3.0
2-8-19	5.0%	9.0%	20.0%	60.0%	6.0%	2	0.826	2276	0.9
2-8-20	3.0%	9.0%	20.0%	60.0%	8.0%	2	0.874	2179	0.3
2-7-2(a)	10.0%	10.0%	20.0%	60.0%		2	1.968	2158	6.1

TABLE 5(c): TEST OF STRENGTH DEVELOPMENT OVER TIME
(weight percentages)

			AGGREGATE		Testing	L/D	Density	Strength
	GP(A)	GP(B)	Coarse	Fine	Age	Ratio	(kg/cu. m)	(MPa)
4-7-2	4.7	7.8	50	37.5	3	2.0	2374	13.7
4-7-2	4.7	7.8	50	37.5	7	2.0	2392	19.8
4-7-2	4.7	7.8	50	37.5	31	2.0	2390	33.6
4-7-2(a)	4.7	7.8	50	37.5	31	2.1	2461	9.4

NOTE: Water added to cylinder 4-7-2(a)

TABLE 6: MIX DESIGNS USING DIFFERENT BINDERS AND AGGREGATES IN CONCRETE MIXES
(constituents as weight percent)

	GPA LIQUID	IB7030 LIQUID	IB CTIVATOR	INORBOND TYPE D	INORBOND TYPE F	SILICA FUME	SLAG	CaF2	SAND	PEA GRAVEL	SET TIME
3-16-1	23.8%		9.5%	9.5%					28.6%	28.6%	5 min
3-16-2	23.8%		4.8%	9.5%			4.8%		28.6%	28.6%	Next day
3-16-3	23.8%		3.8%	9.5%		1.0%	3.8%	1.0%	28.6%	28.6%	Next day
3-16-4	20.0%		3.2%	4.0%		0.8%	6.0%	2.0%	40.0%	24.0%	Next day
3-16-5	20.0%		4.0%	5.0%		1.0%	7.5%	2.5%	30.0%	30.0%	Next day
3-16-6	21.4%		2.9%	3.6%		0.7%	5.4%	1.8%	42.9%	21.4%	Next day
4-3-1	23.1%		9.3%		9.3%				58.3%		20 min.
4-3-2	23.1%		9.3%		9.3%				58.3%		25 min.
4-1-3	16.3%		6.5%		6.5%				65.1%		20 min.
12-15-1		20.8%		8.3%		0.8%	4.2%	3.3%	62.5%		30 min.
12-15-2		20.8%		8.3%		0.8%	5.0%	2.5%	62.5%		30 min.
12-15-3		9.5%		9.5%		1.0%	6.7%	1.9%	71.4%		30 min.
12-15-4		9.5%		9.5%		1.0%	2.9%	5.7%	71.4%		30 min.

Table 7(a): Solidification of Iron Hydroxide Sludge
(gram amounts)

	GPA	GPB	Fly Ash	Sand	Sludge	Total
H-1	25	25		50	100	200
H-2	25	25	50	50	50	200
H-3	25	25	75	25	50	200
H-4	15	15	70	25	75	200
H-1a	25	25			150	200
H-1b	12.5	12.5	50		150	225

Table 7(b): Solidification of Iron Hydroxide Sludge
(weight percentages)

	GPA	GPB	Fly Ash	Sand	Sludge	Comments
H-1	12.5%	12.5%		25.0%	50.0%	
H-2	12.5%	12.5%	25.0%	25.0%	25.0%	Sample sent to P. Goudey
H-3	12.5%	12.5%	37.5%	12.5%	25.0%	Sample sent to P. Goudey
H-4	7.5%	7.5%	35.0%	12.5%	37.5%	Sample sent to P. Goudey
H-1a	12.5%	12.5%			75.0%	
H-1b	5.6%	5.6%	22.2%		66.7%	

TABLE 1

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-7-1	Feb. 7	Feb. 9	2 Day Dry Cure	0.883	2408	-	13.9
2-7-2	"	"	"	0.880	2211	-	2.7
2-7-3	"	"	"	0.946	2303	-	9.4
2-7-4	"	"	"	0.882	2142	-	6.3
2-7-5	"	"	"	0.883	2295	-	5.7

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-7-1: 4.67 cm; 2-7-2: 4.68 cm; 2-7-3: 4.67 cm; 2-7-4: 4.67 cm; 2-7-5: 4.68 cm.

MAXIMUM AGGREGATE SIZE: "Pea" Gravel.

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders approximately 4.2 cm high.
Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 2

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-7-6	Feb. 7	Feb. 9	2 Day Dry Cure	0.875	2331	-	3.9
2-7-7	"	"	"	0.916	2354	-	16.2
2-7-33	"	"	"	0.884	2243	-	1.9
2-7-34	"	"	"	0.896	2214	-	4.6

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-7-6: 4.68 cm; 2-7-7: 4.67 cm; 2-7-33: 4.67 cm; 2-7-34: 4.67 cm.

MAXIMUM AGGREGATE SIZE: "Pea" Gravel.

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders approximately 4.2 cm high.
Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 3

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-8-9	Not Provided	Feb. 10	2 Day Dry Cure	0.894	2174	-	2.6
2-8-10	"	"	"	0.875	2219	-	0.9
2-8-11	"	"	"	0.879	2178	-	0.9
2-8-13	"	"	"	0.852	2216	-	1.8
2-8-14	"	"	"	0.885	2225	-	1.3

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-8-9: 4.65 cm; 2-8-10: 4.65 cm; 2-8-11: 4.66 cm; 2-8-13: 4.68 cm; 2-8-14: 4.65 cm.

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 4

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
2-8-15	Not Provided	Feb. 10	2 Day Dry Cure	0.842	2224	-	0.9
2-8-17	"	"	"	0.884	2243	-	3.2
2-8-18	"	"	"	0.880	2265	-	3.0
2-8-19	"	"	"	0.826	2276	-	0.9
2-8-20	"	"	"	0.874	2179	-	0.3

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 2-8-15: 4.66 cm; 2-8-17: 4.65 cm; 2-8-18: 4.65 cm; 2-8-19: 4.63 cm; 2-8-20: 4.57 cm.

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinders provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 4

CYLINDER
COMPRESSIVE STRENGTH ~~CORE~~ TEST REPORT

DATE: APRIL 10, 1989

PROJECT: COMPRESSIVE STRENGTH TESTING PROJECT NO: 891-1111

CLIENT: D. COMRIE CONSULTING LTD.

LOCATION ON PROJECT: -

Core No.	Date Sampled	Date Tested	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
1-7-2	-	Apr. 10/89	DRY	2.0	2374	-	13.7

DIRECTION APPLIED LOAD: AXIAL
DIAMETER OF CORE: 10.2 cm
MAXIMUM AGGREGATE SIZE: 19 mm ?
APPROXIMATE CONCRETE AGE: 3 DAYS
APPEARANCE: CYLINDER CONTAINED HONEYCOMBED AREAS ON EXTERIOR
REMARKS: OF CYLINDER 1

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 5

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4" x 8"	Not Provided	Feb. 10	2 Day Dry Cure	1.968	2158	-	6.1

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: -

APPROXIMATE CONCRETE AGE: 2 days

APPEARANCE:

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 5

CYLINDER

COMPRESSIVE STRENGTH ~~CORE~~ TEST REPORT

DATE: APRIL 10, 1989

PROJECT: COMPRESSIVE STRENGTH TESTING PROJECT NO: 891-1111

CLIENT: D. COMRIE CONSULTING LTD

LOCATION ON PROJECT: —

Core No.	Date ~~Sampled~~ CAST	Date Tested	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	APR. 7/89	APR. 14/89	DRY	2.0	2392	—	19.8

DIRECTION APPLIED LOAD: AXIAL

DIAMETER OF CORE: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19mm?

APPROXIMATE CONCRETE AGE: 7 DAY

APPEARANCE: CYLINDER CONTAINED HONEYCOMING ON EXTERIOR FACE.

REMARKS:

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 6

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4" x 8"	Not Provided	Apr. 7	Dry	2.0	2310	-	5.2

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm

APPROXIMATE CONCRETE AGE: Not provided

APPEARANCE: Shrinkage cracks noted on ends only.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 7

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	Not Provided	Apr. 10	Dry	2.0	2374	-	13.7
(4"x 8")							

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm

APPROXIMATE CONCRETE AGE: 3 days

APPEARANCE: Cylinder contained honeycombed areas on exterior.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 8

COMPRESSIVE STRENGTH CYLINDER TEST REPORT

DATE: May 3, 1989

PROJECT: Compressive Strength Testing of Mini Cylinders

PROJECT NO: 891-1111

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

Cylinder No.	Date Sampled 1989	Date Tested 1989	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2	Apr. 7	Apr. 14	Dry	2.0	2392	-	18.3
(4"x 8")							

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CYLINDER: 10.2 cm

MAXIMUM AGGREGATE SIZE: 19 mm ?

APPROXIMATE CONCRETE AGE: 7 days

APPEARANCE: Cylinder contained honeycombing on exterior face.

REMARKS: Cylinder provided to us.

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

TABLE 9

CYLINDER

COMPRESSIVE STRENGTH ~~CORE~~ TEST REPORT

DATE: May 12/1989

PROJECT: Compressive Strength Testing of 4"x8" Cylinders

PROJECT NO:

CLIENT: D. Comrie Consulting Ltd.

LOCATION ON PROJECT:

~~CYLINDER Core~~ No.	Date ~~Sampled~~ SUPPLIED	Date Tested	Test Condition	L/D Ratio	Density (kg/m^3)	Specified Strength (MPa)	Compressive Strength (MPa)
4-7-2-A	May 8/89	May 8/89	DRY	2.1	2390	/	33.6
4-7-2-B	"	"	"	2.1	2461	/	9.4

DIRECTION APPLIED LOAD: Axial

DIAMETER OF CORE: 10.1 cm ; 10.1 cm

MAXIMUM AGGREGATE SIZE: —

APPROXIMATE CONCRETE AGE: ?

APPEARANCE: Good.

REMARKS:

TESTS WERE PERFORMED IN ACCORDANCE WITH CAN 3-A23.2-14C M77

APPENDIX 3. PROGRESS REPORTS-PHASE 1 WORK

camrie

INTERIM REPORT 1

Source: HALREPT1

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Mix Designs

Several preliminary tests have been conducted to evaluate the performance of geopolymer when combined with various constituents. Fly ash, silica fume, clay and sand have been used in different proportions, as shown in the enclosed table. Where necessary, water has been added for ease of mixing.

These mixes serve to provide an indication of the effect of including different constituents with geopolymer, and form a basis from which mix designs can be developed.

Samples were qualitatively evaluated on the basis of compressive strength, hardness (Moh's scale), the consistency of the wet mixture and the ability of the mix to conform to the surfaces of a mold (mouldability). Since the aim of this program is to develop a mix which can be applied to an irregular surface (i.e., pyritic slates), it is worthwhile examining this ability to conform.

The contributions made by individual constituents are discussed below.

Fly Ash

A relatively low temperature fly ash was obtained from Ontario Hydro's Lakeview generating station in Mississauga.

The addition of large amounts of fly ash requires corresponding large amounts of moisture in the mix. If the geopolymer itself does not provide sufficient moisture, relatively large volumes of water must be added. Since water acts to weaken the strength and hardness of the final product, this addition poses a problem.

camria

INTERIM REPORT 2

Source: HALREPT2

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Several preliminary tests have been conducted to evaluate the performance of geopolymer when combined with various constituents. Fly ash, silica fume, clay and sand have been used in different proportions, as shown in the enclosed table. Where necessary, water has been added for ease of mixing.

These mixes provide an indication of the effect of including different constituents with geopolymer. The next phase of this program will involve systematic development of mix designs using these constituents.

Samples were qualitatively evaluated on the basis of compressive strength, hardness (Moh's scale), the consistency of the wet mixture and the ability of the mix to conform to the surfaces of a mold (moldability). Since the aim of this program is to develop a mix which can be applied to an irregular surface (i.e., pyritic slates), it is worthwhile examining this ability to conform.

The contributions made by individual constituents are discussed below.

Fly Ash

A relatively low temperature fly ash was obtained from Ontario Hydro's Lakeview generating station in Mississauga.

The addition of large amounts of fly ash requires corresponding large amounts of moisture in the mix, which can result in a product of lower strength and hardness. Mixtures containing up to 60 weight percent ash and 40 weight percent geopolymer (on a dry weight

basis) have produced solids of high strength and hardness.

Mixtures with higher ash contents can be achieved by pre-mixing geopolymer with the fly ash. Normally, wet and dry ingredients in the geopolymer are combined in a 1:1 ratio. An ash-based geopolymer employing 50 weight percent geopolymer liquid, 30 weight percent fly ash and 20 weight percent geopolymer powder was used for a number of mixes. Compositions with as little as 13 weight percent of this ash-based geopolymer and 69 weight percent additional ash (on a dry weight basis) have produced solids, although at some considerable expense of set-up time, strength and hardness.

Sand Content

A fine, commercially available playbox sand of moderate purity was employed in the testing.

A comparison of mixes incorporating sand with mixes solely composed of geopolymer and fly ash demonstrates that sand acts to increase strength, hardness and improves ease of mixing.

The use of sand in silica fume based mixes also increases strengths, and also results in increased moldability. Replacing a portion of clay with sand in clay based mixes also results in improved strength and hardness.

Clay Content

A fine, dry (but uncalcined) montmorillonite clay (Tennessee No. 5, with an Al_2O_3/SiO_2 ratio of 2.11) was employed in some mix designs.

As expected, the substitution of sand by clay requires more water to be added to the mix and results in samples of lower hardness and strength. Similar relations are observed in the substitution of clay for fly ash. However, the use of clay in the place of fly ash does seem to increase the moldability of the mixture.

Increasing clay content at the expense of sand also results in decreased strengths and mixes of an increasingly paste-like nature.

Silica Fume

The addition of silica fume imparts a grainy texture to the mix, making mixing easier and requiring less water. Where silica fume is added at the expense of sand, more water is required for mixing but a product of higher strength and hardness results.

Water Content

Mixtures have been prepared both with and without water. Dry or paste-like mixtures, having only the moisture provided by the geopolymer, are difficult to mix and are more suitable for extrusion molding processes. Wet mixes are more easily mixed and can be designed to produce consistencies ranging from mortar-like to a syrup.

Water, in large proportions, will of course dilute the geopolymer and render the mixture useless. However, small increases in the amount of water can produce dramatic changes in the consistency of the mix. An increase of as little as 5 weight percent water can make the difference between a dry, paste-like mixture and a smooth, easily molded mixture.

Summary

Two types of criteria have been used to asses the mixing done to date: physical characteristics (moldability of the mixture, strength and hardness of the final product) and economics (represented by the ratio of geopolymer to other filler ingredients). Based on this criteria, mix H-8 stands out as the best performing, containing 20 weight percent (on a dry basis) geopolymer, as shown below:

Mix Design	GP (%)	Ash (%)	Sand (%)	Fume (%)	Water (%)
H-8 (dry basis)	20	20	20	20	-
H-8 (wet basis)	17	17	17	17	15

The next step in the project will be a systematically engineered mix design, which will be based, in part, on the data collected so far.

canmet

INTERIM REPORT 3

Source: HBILL2
Date: February 21, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Work reported in this period includes a meeting in Ottawa with the Scientific Authority, followed by preparation of a number of geopolymer based mixes.

A meeting was held on February 1 with the Scientific Authority in order to discuss the progress made to date on the project, and the direction which it should proceed in from this point. Technical tests, such as freeze/thaw and permeability, which will be carried out on the samples produced during the contract, were also discussed.

Several mixing programs were developed, each designed to evaluate the effect of different factors. A number of samples were made for each program, and the results of compressive strength testing on these samples will be used to define curves based on the following variables:

1) Compressive strength as a function of geopolymer content
2) Compressive strength as a function of percent coarse aggregate in the total aggregate fraction.
3) Effect of fly ash on compressive strength when substituted for the powder portion of geopolymer.
4) Effect on compressive strength when the liquid portion of geopolymer is reduced.
5) Effect of fly ash on compressive strength when substituted for the liquid portion of geopolymer.

Several other variables have yet to be evaluated in the mixing program.

canmrie

INTERIM REPORT 4

Source: HALFX4

September 29, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Time has been expended on the Physical Testing and Application Trials portions of the project. Discussions have been held with the Scientific Authority and with concrete contractors in order to prepare for both physical testing and a "field test" of various mixes for shotcreting.

Freeze Thaw molds have been requested of, and received from, CANMET in Ottawa. Beams will be poured following the actual shotcreting test, assuming that the mix designs perform satisfactorily under shotcreting.

comrie

INTERIM REPORT 5

December 4, 1989

PROGRESS REPORT

Contract Title: To develop geopolymer formulations and to determine their mechanical and durability properties for capping of pyritic slate outcrops at Halifax airport.

Contract No: 23440-8-9171/01-SQ

Work conducted during this period concentrated on a field application of inorganic binder using shotcreting technology. This was considered immensely successful, since it was found that high pressure pumping of the liquid and solid portions of the binder allowed delivery of a quick setting mixture with minimal amounts of the binder liquid (representing the more expensive component). The liquid:solid ratio represents a dramatic improvement over ratios which have been previously worked with on a bench scale.

Standard 8-inch ASTM cylinders were cast with binder pumped out of shotcreting apparatus, and six beams were poured for freezing and thawing tests. After moist curing under burlap, the cylinders and four of the beams were delivered to CANMET's Materials Testing laboratories in Ottawa. Unconfined compressive strength tests will be conducted on the cylinders; the beams will be subjected to rapid freeze-thaw testing. Two beams were retained at Comrie Consulting in case beams were damaged en route to Ottawa or during the freeze-thaw testing.